2024

BOOK OF ABSTRACTS

EDITED BY

TERESA BATISTA

TIAGO PINHO

JOÃO CORREIA

Digital and Green Transition in Maritime Ports: Trends and Challenges

DGTMP'24 - NEXUS INTERNATIONAL CONFERENCE Book of Abstracts

Edited by

Teresa Batista

Tiago Pinho

João Correia

ISBN 978-972-778-413-4

Published by

UNIVERSIDADE DE ÉVORA

Colégio Luis António Verney

Rua Romão Ramalho, 59

7000-671 Évora – Portugal

https://www.nexusconference.uevora.pt

1.st Edition, June 2025.

We thank all the authors for their contributions and the Abstract reviewers from the scientific and organizing committees for their invaluable feedback.

The Editors.

To cite this abstract book:

Batista, T., Pinho, T., Correia, J., (Eds.). (2025). *DGTMP24 Book of Abstracts.,* University of Évora.

To cite an individual abstract:

[Author(s)]. 2025. [Title of the Abstract]. In: *DGTMP24 Book of Abstracts.,* Batista, T., Pinho, T., Correia, J.,(Eds.). [page numbers], June. Évora, Portugal.

FOREWORD

In these difficult times the world is facing multiple challenges, in human society and world biodiversity. Climate Change and the intensification of extreme events creates huge challenges in worldwide institutions (United Nations, ONGs, Humanitarian institutions), food crises, health crises, and massive population migrations. Geopolitical instability and army conflicts spread out, affecting the economy and producing social instability. Digitalization and Artificial Intelligence spread out across all economic sectors (agriculture, industry, transports and logistics).

Achieving sustainability becomes more and more important in every sector, and even more in the case of maritime industry, as maritime transport handles almost 90% of the global trade. Nevertheless, almost 99% of the global vessels fleet remains reliant on conventional fuels, accounting for 3,6% of the global greenhouse gas (GHG) emissions, which has increased by 20% in the last decade.

The Port of Sines is the most important maritime infrastructure in Portugal, it accounts for more than 94% of the Natural Gas Energy entering the country (REN 2022) and it is responsible for more than 50% of the containerized cargo managed in Portugal, holding the 14º position in container cargo handling in Europe (Notteboom, 2022).

NEXUS Agenda (https://nexuslab.pt/) is the innovation project led by the Port of Sines and Algarve Authority (APS) that has the ambition to promote the Digital and Green Transition at the Port of Sines.

The **NEXUS International Conference - Digital and Green Transition in Maritime Ports - Trends and Challenges (DGTMP2024),** is an important milestone in the development of the NEXUS Agenda, building the environment for sharing research advances and trends on **digital logistics and sustainable mobility in ports** between the scientific community, technological partners and stakeholders.

Organized by the University of Évora and the APS, in partnership with IPS – Polytechnic Institute of Setubal, University of Coimbra and University of Aveiro, the **NEXUS International Conference** has been hosted by the University of Évora and the Port of Sines and Algarve Authority, for four days, from 10 to 13th December 2024, in Évora and Sines.

The conference explored the latest trends, technologies and strategies that are shaping ports operation and management. On one hand, **digital logistics** provides the tools to optimize processes, reduce costs and improve the traceability of goods. From warehouse automation to intelligent management of terminals, gates and containers, digitalization is transforming the supply chain and empowering efficiency in ports. On the other hand, the **green transition** has become an unavoidable priority. The electrification of ports, the energy transition, fuel replacement and emission reductions are essential to ensure a cleaner and more resilient future.

In the two days at the University of Évora, the conference had more than 200 participants, from several countries. It involved 54 communications, 28 oral presentations and 26 posters, organized in four topics: Digital Transition and Decarbonization in Maritime Ports; Energy Transition; Sustainability in Ports; and Smart Ports, Logistics and Training.

The Nexus International Conference – DGTMP24, proved to be a significant milestone in the field of knowledge and innovation in seaports, bringing together experts, academics and professionals from various parts of the world. The presence of renowned invited speakers and moderators such as Adil Ait Oualil, Eduard Rodes, José Santos, Luis Manuel Navas, Maurice Jansen, Rodrigo Ramirez, Stephanie van den Berg, Hans Rook and Vitor Caldeirinha as well as the dynamic format of the sessions, allowed for an interactive environment, where participants could not only absorb valuable knowledge, but also share their experiences and research results.

One of the great highlights of the conference was its ability to promote networking among participants. In an increasingly interconnected global scenario, the Nexus conference was a crucial meeting point for those seeking international partnerships, the exchange of ideas and the creation of new opportunities for collaboration. By bringing together academics, industry professionals and other stakeholders, the conference was a true catalyst for strengthening contact networks, both nationally and internationally, also bringing together several researchers from Ibero-America on the CYTED networks journey.

Furthermore, the choice of locations such as the University of Évora, with a very rich academic and architectural history, and the Port of Sines, with a new and modern infrastructure (Cyber Gym), also contributed to the success of the event. The environments proved to be inspiring and provided a positive experience, which facilitated interactions between participants during the various sessions.

The success of DGTMP24 reflects not only the impact of academic discussions and developments, but also the University of Évora's commitment to contributing to the advancement of global knowledge and strengthening international collaboration in sustainable transport and mobility. The conference was undoubtedly an event of great importance, with lasting impacts on research and development networks and the promotion of innovative solutions to the contemporary challenges of seaports.

The Editors,
Teresa Batista
Tiago Pinho
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CONFERENCE FUNDING

This conference was funded by the PRR - Recovery and Resilience Plan, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação, Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project no. 53 with the application C645112083-00000059).

DGTMP24 Conference Participants at University of Évora – Portugal (Dez, 2024).

CONTENTS

DIGITAL TRANSITION AND DECARBONIZATION IN MARITIME PORTS

Hans Rook
Ambassador of the International Port Community Systems Association (IPCSA)
Keynote speaker

This is a special moment to proclaim our vision and continuous effort to both science and the transport logistics sector to reduce CO2 emissions to the lowest possible level.
This as a basis, I would first like to apologize to 'Mother Earth'.

Mother Earth I see tears in your eyes, you have given us a beautiful nature that forms the basis for our daily life. A basis that we as humanity have grabbed with both hands, but unfortunately our greed for constant economic growth, a world where we want more and more, has led to a situation that is proving unsustainable for future generations.

You have extended a helping hand to us and we have ultimately, unsuspectingly, abused it. And listening..., realizing..., has taken a very long time. This while in the previous century, in 1976, Al Gore, former vice president of the USA, already gave us a first warning. But unfortunately, we did not realize why.

In 1997, the historical climate agreement was recorded in Kyoto, which could only be agreed to in 2005, a protocol but too less exposure to all of us by the government agencies.

In 2006, we were alarmed by the hole in the ozone layer. We were shocked for a moment, but unfortunately that was only for a moment because we did not notice the tangible negative effects at that moment.

For me too, they were just signals, without paying attention to them. But also in 2006, Danis Gugelheim produced the documentary in which Al Gore again played the leading role: 'An Inconvenient Truth'.

An American documentary film, featuring the multimedia presentation of former U.S. vice president Al Gore that formed the basis for his traveling lecture tour on the emerging human challenge of global warming and climate change.
That really made me think, not only seen from my private life, but also from our profession. Transport logistics.

What does our contribution mean for climate change. And then comes the realization that we can make a major contribution to a cleaner, improved nature that we all love so much.

A logistical journey for the benefit of our ecosystem.

Our view concentrates on the use of Port Community Systems and Single Window solutions to enhance the Trade Facilitation.

Port Community System usage means collaboration between the many stakeholders involved in and around the port. Collaboration is essential for our aims to enhance the quality of processes and data that results in a significant contribution to a better time to market situation and consequently to lower emissions and better emission values.
More specific I would like to highlight a few aspects that will support our goals:

- Digitalisation: The Backbone of Modern Trade
- Smart Technologies: Enhancing Efficiency and Performance
- Connectivity: Linking Global Supply Chains
- Decarbonisation: Advancing Sustainability in Trade
- Digitalisation: The Backbone of Modern Trade

Digitalisation lies at the heart of PCS, providing a foundation for integrating various technologies that enhance port operations. Through digital platforms, PCS facilitates real-time data sharing and collaboration among stakeholders. This not only speeds up processes but also reduces errors associated with manual data entry and documentation. For instance, the digitalisation of customs procedures through PCS has led to faster clearance times as information is processed and verified electronically, reducing the need for piles of paper, a lot of physical travel through the port area, easier (electronic) archiving and more focus on control.

Furthermore, the digitalisation of port operations allows for better tracking and monitoring of cargo. Using advanced technologies, PCS can provide real-time updates on cargo location, status, and condition. This transparency helps in better decision-making and planning, reducing bottlenecks and delays in the supply chain.

Smart Technologies: Enhancing Efficiency and Performance
Smart technologies are integral to the functioning of PCS, enabling ports to operate more efficiently and respond dynamically to changing conditions. These technologies include automated systems for cargo handling, smart sensors for real-time data collection, and advanced analytics for predicting and mitigating potential disruptions.
For example, the load and discharge planning, the handling of the cargo on container terminals, and the planning of the inland transport supported through PCS through excellent standardised and harmonised data have significantly improved the usage of the assets for efficiency of cargo handling, reducing dwell times and faster delivery to the receiver of the cargo.

Connectivity: Linking Global Supply Chains
Connectivity is another key aspect of PCS, enabling seamless integration across the entire supply chain. Ports do not operate in isolation; they are part of a global network of logistics and transportation systems. PCS can facilitate this connectivity by integrating with other digital platforms. Not to forget the Single Window systems used by national government agencies and international public organisations.
When integrated with PCS as a single point of entry, it further streamlines the trade process by reducing the duplication of data entry, consequently minimising delays and because of that the trade facilitation is brought to a high level of efficiency.

Decarbonisation: Advancing Sustainability in Trade
Sustainability has become a critical concern in global trade, with increasing pressure on industries to reduce their carbon footprint. The maritime industry, in particular, is under scrutiny for its environmental impact, as shipping accounts for a significant portion of global greenhouse gas emissions. PCS can play a pivotal role in advancing decarbonisation efforts by optimising port operations and reducing energy consumption.

One of the ways PCS contributes to decarbonisation is by facilitating the efficient scheduling of ships (just-in-time process) and cargo handling operations as well at the terminal as in the inland haulage traffic. By minimising waiting times and ensuring that ships spend less time idling at ports, PCS usage supports in reduction of fuel consumption and associated emissions. Additionally, the integration of smart grid technologies within PCS allows ports to better manage their energy use, incorporating renewable energy sources and reducing reliance on fossil fuels.

Moreover, PCS supports the implementation of green logistics practices by providing the data needed to optimise supply chains for sustainability.

IPCSA believes that Community systems like PCS's and Single Windows play a vital role in the logistics digital ecosystem and can accelerate the adoption and scale of digitalisation.

Port Community Systems have emerged as a major game changer in trade facilitation, transforming the way ports operate and interact with the global supply chain. IPCSA, as a neutral body, plays an essential role in influencing the conditions for PCS and Single Windows to operate. Through digitalisation, smart technologies, connectivity. PCS has significantly enhanced the efficiency, transparency and sustainability of port operations. By embracing these systems and overcoming the associated challenges, ports around the world can contribute to a more connected, efficient, and sustainable global economy.

If we all put our shoulders to the wheel, we will succeed. And by all I don't mean locally but globally.

Mother Earth, I hope that my words will be translated into actions and not just a snapshot, but for a longer period, in fact an infinite period.

I see a sparkle in your eyes again.

We will all make this come true for the future of our children, grandchildren and many generations that will follow.

A systematic review of visualisation tools for open data

Bárbara Nascimento [1,*], Jéssica Parente [2,*], Evgheni Polisciuc [2] and João Correia [2]

[1] CISUC/LASI, Institute for Interdisciplinary Research, University of Coimbra. E-mail: barbararamos@dei.uc.pt
[2] CISUC/LASI, DEI, University of Coimbra. E-mail: jparente@dei.uc.pt; evgheni@dei.uc.pt; jncor@dei.uc.pt
* Correspondence: barbararamos@dei.uc.pt; jparente@dei.uc.pt

Abstract: This study analyses visualisation methods used in open data platforms and reviews relevant literature in the same context. The objective is to evaluate the effectiveness of these tools and identify opportunities for creating more sophisticated and user-friendly visualisations for open data. Using a PRISMA-based systematic review, we examined 330 open data platforms and 142 academic papers. Our findings reveal a basic range of visualisation techniques, highlighting the need for greater variety, customisation, complexity, and interactivity. Addressing these areas can enhance user satisfaction and improve the overall effectiveness of visualisation in open data.

Keywords: open data; open data platform; visualisation; open data visualisation

1. Introduction

Over the years, many governments and organisations have made their data publicly available for transparency and economic development, creating several open data platforms [1, 2, 3]. The published data, known as Open Government Data (OGD), refers to data produced or commissioned by government bodies and made available to the public, primarily through dedicated portals [4, 5]. Notable OGD portals include those in the US (data.gov), UK (data.gov.uk), Taiwan (data.gov.tw), France (data.gouv.fr), and Singapore (data.gov.sg). These portals simplify users' access to government data, eliminating the need to navigate through multiple agencies, offices, or websites. Despite these open platforms, it can be challenging for the public to understand and draw conclusions from the data. To address this issue, visualisation techniques can be used on open datasets. These visualisations can transform complex data into formats that are more accessible and easier to comprehend, enabling users to recognise patterns, trends, and outliers more easily. Furthermore, effective visualisations can boost user engagement and facilitate a deeper understanding of the data, which enables citizens to make well-informed decisions. In this context, our study focuses on analysing visualisations found in open data platforms and reviewing literature that proposes visualisation methods for these platforms. The objective is to evaluate the current state of the art in this field, identify standard practices, specify gaps, and explore potential areas for improvement.

This analysis will offer insights into the effectiveness of existing visualisation tools and uncover opportunities for creating more sophisticated and user-friendly visualisations for open data.

2. Methods

We conducted a PRISMA-based systematic review [8] of open data platforms and a literature review on the same topic. After a thorough screening process, the PRISMA-based review collected a total of 330 open data platforms and 142 scientific papers.

A. Platforms analysis

In the first phase, we excluded platforms that did not offer visualisation tools. Of the 330 platforms, 68 were eligible for the second phase. In the second phase, the platforms were classified and analysed based on the visualisation techniques offered, the customisation level of the visualisations, and the interaction technique. At the end of the second phase, 13 platforms were rejected for not being open access. Thus, 55 platforms were analysed and chosen at the end of the research.

B. Papers analysis

For the paper analysis, we used the following databases to gather the largest number of relevant publications: ACM Digital Library, IEEE Xplore Digital Library, ScienceDirect, and Scopus. We selected papers tagged with "open data platform" and "open data visualisation" in the title, keywords, or abstract. From the survey papers identified, additional relevant publications were also selected, culminating in a total of 142 papers. In the first phase, we conducted a preliminary review and excluded papers that were not relevant to the search topics or did not incorporate visualisation techniques. Of the 142 papers, 60 were eligible for the second phase. In the second phase, the remaining papers were analysed in detail and categorised by topic: (i) papers on open data platforms; (ii) papers presenting visualisations of specific open datasets; (iii) papers on platforms or applications designed specifically for receiving open datasets and creating visualisations; and (iv) studies on open data, including surveys.

To enable comparison between platforms and papers, we excluded the study papers and the ones that only had geographic-level visualisations. We also ended up excluding 7 papers related to linked open visualisation because the main goal in this work was off our main topic. Of the 60 papers from the first phase, only 24 were analysed and classified using the same criteria as the platforms.

C. Analysis setup

The platforms and papers were classified into five dimensions:

- **Visualisation technique by function:** We have classified all the visualisation techniques available on the platform according to their function: comparisons, part-to-a-whole, relationships, patterns, data over time, and others. The aim is to understand whether the visualisations offered are limited to a restricted number of analysis types or offer a wide range of options for the end user.
- **Visualisation technique by data type:** Based on Shneiderman's work [9], we classified the visualisation techniques offered by data type, i.e. whether the visualisations are 1 dimension, 2 dimension, 3 dimension, multidimensional, Tree, Network or Temporal.
- **Visualisation technique:** We also made a list of the types of graphics offered so that in the future, we could compare them with the techniques divided by function and data type.
- **Interaction techniques:** To analyse interaction techniques, we used the seven interaction techniques for visualisation proposed by Yi[10]: Select, Explore, Reconfigure, Encode, Abstract/elaborate, Filter and Connect.
- **Level of customisation:** We have categorised visualisations into three levels of customisation. The first level has minimal customisation options like changing colours or titles. The second level offers more customisation, such as changing graphic types, colours, and titles. The third level provides extensive customisation, including data classification, scale, chart type, colours, titles, legends, data grouping, and parameters.

3. Results and Discussion

A. Platforms analysis

The analysis of the 55 open data platforms revealed low variability in the availability of visualisation tools. The platforms could be divided into four groups, three based on the APIs used, and one group included platforms that exhibited more variance in the interaction techniques and types of visualisations offered. The platforms were evaluated based on the five aspects mentioned earlier: (i)visualisation technique by function, (ii)visualisation technique by data type, (iii)visualisation technique, interaction techniques, and (iv)level of customisation.

Firstly, regarding the **visualisation technique by function**, most platforms offered basic comparison and part-to-a-whole (100%, or 55 platforms) visualisations, such as bar charts and pie charts. 96.36% (53 platforms) offered part-to-a-whole and data over time charts, 94.55% (52 platforms) offered proportion charts, 76.36% (42 platforms) offered distribution charts, 18.18% (10 platforms) offered relationship charts, and 14.55% (8 platforms) offered range and hierarchy charts. These results show that more complex visualisation types, such as those depicting relationships or hierarchies, were less common, indicating a potential gap in the ability of these platforms to support more sophisticated data analysis needs. For the **visualisation technique by data type**, while all platforms support 1D and 2D data visualisations, only 14.55% (8 platforms) accommodate three-dimensional or multidimensional data. This suggests that while basic data types are well supported, there is space for improvement in accommodating more complex data structures with more dimensions. No platforms were observed to contain visualisation options for Tree, Network, or Temporal data types. The evaluation of **visualisation techniques** showed a prevalence of traditional charts, such as bar charts, line charts, scatter plots, and pie charts. Visualisations like heat maps, Nightingale rose charts, radar charts, scatterplots, and treemaps were less frequently available in only seven platforms (12.73%). Multidimensional data visualisations, such as parallel coordinates, were not found.

Regarding **interaction techniques**, most platforms utilised only one or two, the most common being filter (94.55%, or 52 platforms) and reconfigure (90.91%, or 50 platforms). The reconfiguration interaction was mainly considered by adding series to the chart and sorting the data. Other interaction techniques were encoded (14.55%, or 8 platforms) through the possibility of changing the chart colours and exploring (12.73%, or 7 platforms) through actions such as panning and zooming on the chart. Only two platforms offered the option to select (3.64%). No visualisations provided the interaction techniques: abstract/elaborate, select, or connect. Two of the analysed platforms had no interaction technique in the visualisations. Approximately 61.8% of the platforms (34 platforms) offered the highest **customisation level**, allowing users to adjust multiple parameters such as changing colours, highlighting parts of the chart, and modifying titles and legends. 16.4% (9 platforms) had a customisation level of 2, and 21.8% (12 platforms) offered no or limited customisation options.

B. Papers analysis

In contrast to the platforms, the analysed papers exhibit significant diversity. Half of them (12 papers) presented visualisations of open data related to different themes, such as socioeconomics, maritime and land traffic, forest fires, finances, energy and health. The other half were on platforms or applications designed specifically for receiving open data and creating visualisations. However, even among papers within the same category, comparison is difficult due to the substantial variation in the goals of each paper. Thus, most of the presented visualisations were not well described, and the documentation typically lacked detailed information on the composition of the dataset. Additionally, the absence of links to the developed tools also complicates drawing conclusions based on the data obtained, which can lead to an incomplete analysis. However, like platforms, articles were evaluated based on the five dimensions mentioned earlier: visualisation technique by function, visualisation technique by data type, visualisation technique, interaction techniques, and level of customisation.

Regarding the **visualisation technique by function**, most papers offered basic comparisons and patterns, such as bar charts and histograms. Even though we removed the papers with only geographic visualisations, we ended up with ten papers with basic location visualisations, like choropleth maps or dot maps. Specifically, 66.67% (16 papers) of the papers offered comparison, 37.5% (9 papers) offered pattern charts, and 20.83% (5 platforms) offered proportion charts. These results show that although we anticipated encountering more complex visualisations in the articles—since many of them focused on specific datasets and could create their own visualisations—this expectation was not met. Regarding the **visualisation technique by data type**, all papers provided visualisations for 1D and 2D data or both, and only four papers presented visualisations for three-dimensional or multidimensional data. Regarding the evaluation by **visualisation technique,** the histograms, bar and line charts and scatterplots were the most prevalent charts.

Regarding **interaction techniques**, filtering (45.83%, 11 papers) and selection (41.67%, 10 papers) were the most frequently used. Regarding the evaluation of **customisation levels**, 75% (18 papers) either offered no customisation options, allowing adjustment of only a single parameter (First level) or did not mention possible changes, implying customisation was likely impossible. This was understandable for papers on visualisations of specific open data, where interaction is unnecessary when the goal is to generate isolated visualisations. The same applies to interaction techniques. This discrepancy complicates the analysis of the articles, as tools developed for public use should be evaluated differently from those designed for personal use.

4. Conclusion

Despite the differences, the results from both platforms and articles reveal several key insights and areas for improvement. Most primarily use basic visualisation techniques, like bar, line, and scatter charts, while more advanced visualisations—such as those showing relationships or multidimensional data—are less common, indicating a potential gap in these tools' ability to support advanced data analysis. Most platforms offer limited interaction techniques, and the articles demonstrate limited use of interactive features. Although most platforms offer high customisation, a significant proportion still provide limited options, restricting users' ability to tailor visualisations to their specific needs—a trend also observed in the articles. Both platforms and articles need to provide more support for complex data types and include detailed documentation on datasets.

Overall, these findings suggest that while there is a solid foundation for visualisation in both platforms and articles, there is significant room for improvement. Improving the variety and complexity of visualisation techniques, expanding interaction possibilities, and increasing customisation options could greatly improve the usefulness and accessibility of open data visualisation tools. In addition, better documentation and accessibility of visualisation tools could provide more valuable insights and promote a deeper understanding of open data among non-specialist audiences.

Acknowledgements: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação - Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with n.º C645112083-00000059 (investment project n.º 53), and co-funded by national funds through the FCT – Foundation for Science and Technology, I.P., under the project/support 2022.15675.CMU

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Bibliometric Analysis and Evaluation of Geographical Visualization Platforms in Seaports

Crismeire Isbaex [1], Francisco dos Reis Fernandes Costa [2] and Teresa Batista[1,*]

[1] MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, Instituto de Investigação e Formação Avançada, Universidade de Évora, Apartado 94, 7002-544 Évora, Portugal. E-mail: cisbaex@uevora.pt

[2] GEOPOINT. francisco.costa@geopoint.pt

* Correspondence: mtfb@evora.pt

Abstract: In port management, Geographic Information Systems (GIS) play a key role in visualizing and integrating data on collaborative management platforms. To facilitate the development of a geographic data policy for the Port of Sines, a bibliometric analysis and systematic review of major global ports providing information on online platforms were conducted. To consolidate knowledge in this area, a systematic literature review was conducted using the PRISMA framework. A survey of datasets and functionalities was carried out on 70 port geographical visualization platforms, with 16 ports including datasets related to smart berth. The literature revealed that integrating GIS platforms into collaborative port systems remains a challenge, due to the personalized nature of each port's decisions regarding data sharing among stakeholders. Overall, the ports of Panama and Jawaharlal Nehru presented the most comprehensive number of functionalities, while the ports of Anchorage and Mobile have more simplified functionalities. The diversity of datasets among ports reflects distinctive information sharing policies, having no direct relation between the number of functionalities and datasets available.

Keywords: Literature review; geographic information system; port management.

1. Introduction

The applications of Geographic Information Technology (GIT), especially Geographic Information Systems (GIS) in maritime ports, play a fundamental role in the digital transition and in improving processes efficiency in the sector. The integration of GIS into port management systems enables coordination and visualization across several intervention areas and scales [1,2], and minimizes inefficiency and congestion in ports, reducing vessel turnaround time through optimized berth allocation and accelerating cargo handling operations [3]. In this context, the incorporation of geographic features into web-based GIS or Geovisualization platforms enables geospatial coordination of port operations, facilitating intuitive understanding and real-time decision-making by stakeholders. Although most ports offer digital services to users [1], such as Single Logistics Window, each port establishes its own sharing information system [4,5]. Port authorities maintain different levels of geographic data access between external and internal users [2].

Geographic visualization in open data platforms contributes to the cooperation among port community stakeholders, facilitating the implementation of intelligent technologies for infrastructure monitoring, cargo flow optimization, and effective resource management. These platforms provide broader and more collaborative access to geospatial information, driving innovation and efficiency through data transparency and interoperability [6]. The integration of GIS platforms with IoT and AI exemplifies support tools that optimize long-term strategic and operational management in ports.

Given this context, the study aimed to systematize existing insights and evaluate GIS applications in web-based visualization platforms of international ports to support the collaborative platform of the NEXUS agenda.

2. Materials and Methods

The bibliographic analysis seeks a theoretical foundation on GIS applications in visualization platforms for maritime ports. This analysis is closely linked with techniques for reviewing studies, citations, and keywords [7]. The steps include:

Identification (I) – database search in Web of Science-WOS and Scopus, including combinations of keywords ("web*" AND ("geograph* information system*" OR "gis" OR "map*")) OR ("gis" AND ("portal" OR "platform*")) OR "open source" OR "spatial*" OR "visualization" OR "interactive") AND (("smart" OR "intelligent") AND ("port" OR "berth" OR "terminal*" OR "maritime"). The terms of keywords found were implemented for co-occurrence network visualization in VOSviewer using the binary counting [8].

Screening (II) – the first refinement included article title, abstract, and keywords. With 707 (WOS) and 1,802 (Scopus) relevant sources, further refinements were applied (20 years of publication, articles in English, and main research areas). The total number of publications was 304 (WOS) and 464 (Scopus) publications.

Eligibility (III) - after screening and reviews, the total number of studies to be discussed in this review was determined, based on systematic reviews and meta-analyses in scoping reviews (PRISMA-ScR) [9]. Based on PRISMA guidelines, 768 publications were initially identified. After the screening and analysis process using Zotero 7.0.7, 156 studies met the review's inclusion criteria.

This study conducted an in-depth examination of GIS applications in web-based interactive visualization platforms (referred to as 'GIS platforms'). A global survey was conducted focusing on official websites of port authorities and government agencies. The analysis examined platforms that provide available geographic data and functionalities to external stakeholders (local communities, researchers, and other interested parties).

The research was initially based on the Lloyds List of the world's 100 largest ports [10], as well as other ports not included in this list. Globally, 70 ports were identified that provide GIS and spatial intelligence. A list of 26 functionalities capable of integrating specific GIS resources on the web was compiled to enable tasks such as visualization, data analysis, mapping, and queries. Two classes of datasets (Land Facilities and Nautical or Navigation Information) were grouped to identify the set of information available on the platform interface. Consequently, a dataset filtering was performed for 16 ports (Jawaharlal Nehru (Asia) [11], Ports of Panama (Central America) [12], Rotterdam [13], Ports of Hamburg [14], Gothenburg [15] (Europe), Oakland [16], Montreal [17], Maryland [18], Tampa Bay [19], Anchorage [20], Mobile [21] (North America), Ports of NSW [22], Fremantle [23], Newcastle [24](Oceania), Itaqui [25], and Ports of Paraná [26] (South America)), which had datasets related to Smart Berth. In this work, GIS platforms encompassing multiple ports under the same port administration or government were considered as a single port platform.

The bibliometric analysis and the survey of GIS platforms served as a baseline exploratory analysis for the collaborative development of the geographic components of the Nexus Open Data Collaboration platform of the Sines Port Nexus Agenda.

3.Results

While keywords play a crucial role in identifying themes central to the study's objectives, a high correlation threshold may prevent the visualization of other pertinent keywords [27]. Consequently, tests were conducted below the threshold of 10 to observe keyword overlap. This approach facilitates the understanding of term interconnections, providing a broader perspective of the research landscape [28]. Keywords are emphasized as vital tools for identifying and grouping studies with similar objectives. In this context, from the extraction of 10,256 items (titles and abstracts), the threshold of 5, has select 330 items (60%) with high correlation. These terms were categorized into four distinct clusters: red (43 items), green (37 items), blue (18 items), and yellow (23 items) (Figure 1).

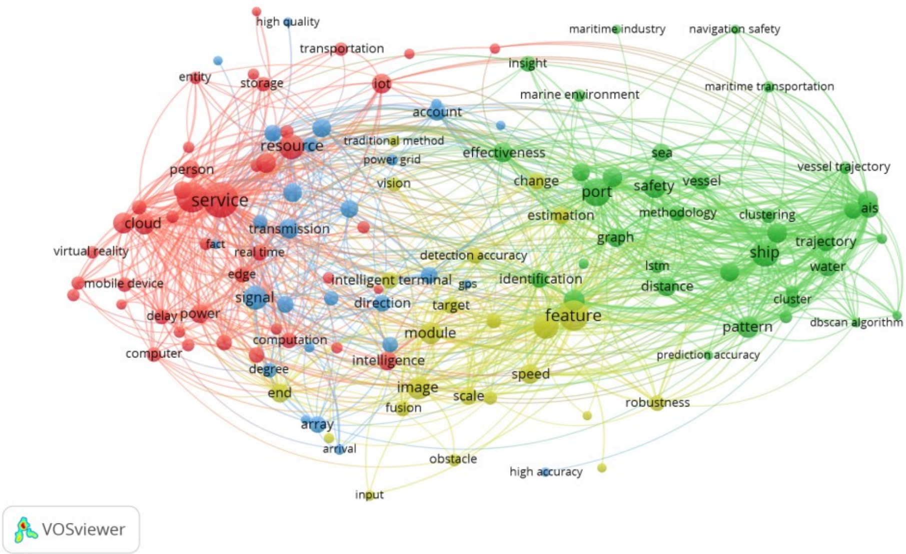

Figure 1. Keywords co-occurrence map.

The literature review revealed a wide range of GIS applications in several operational and strategic aspects, categorized into key topics such as: big data management [29–31]; real-time ships location tracking through automatic identification system (AIS) [32–34]; information and communication technology [35–37]; internet of things [38,39]; and artificial intelligence [40,41]. Recent studies have employed GIS to assist in the spatial analysis of vessel berthing and unberthing [42], in determining berthing positions [43], and Li et al. [44] in integrating AIS data with port information to enhance intelligent maritime systems. The diversity of applications demonstrates the crucial role of GIS in modernizing and improving the efficiency of port systems, where the collaborative and data-driven approach remains a complex challenge in the contemporary maritime industry.

In the survey conducted, all platforms offer basic interaction (zoom) and data management (vectors and attribute tables) functionalities. According to the total number of functionalities, Ports of Panama and Jawaharlal Nehru - India, have more comprehensive interactive platforms, while Anchorage - Alaska and Mobile - USA have platforms with simpler interaction (Table 1).

Table 1. List of functionalities of GIS platforms.

Port List	Visualization	Data Layer Management	Editing	Interaction	Total
Anchorange	L	PY	-	Z, PT	4
Mobile	MT	AT, PY, LN	-	PT	5
Oakland	L, SB	PY, PO, LN	M	-	6
Gothenburg	DE, RMO	PO, LL	-	Z, SE	7
Montreal	DE	AT, L	M	Z, PT, DW	7
Paraná	MT, DE, SB	AT, PY, P	-	-	7
Itaqui	MT, DE	AT, PO	M	Z, PT, SE	8
Newcastle	MT, L	AT, PY, PO, LN	-	Z, DW	8
Fremantle	DE, H	AT, PY, F, LL, P	M	Z	9
Hamburg	RMO	AT, PY, F, LL, P	M	Z, PT, SE	9
NSW	MT, H, DE	AT, PY, F, LL, P	-	Z, PT	10
Maryland	L, MT, DE, SB	AT, PO, F	M, D	Z, PT, SE, DW	12
Rotterdam	L, MT, DE, SB	AT, PY, LN, PO, LL	-	PT, SE	12
Tampa Bay	L, H, DE, SB, C, ML	AT, PY, LL, P	D	Z, SE	12
Panama	L, MT, H, DE, SB, C, RMO, ML	AT, PY, PO, LN, F, LL, P	M	Z, PT, SE	19
Jawaharlal Nehru	L, MT, H, DE, C	AT, PO, LN, PO, F, LL	M, MD, MA, D	Z, PT, SE, PR, SH, U	21

Legend: *Visualization* (L=Legend; MT=MapTips; H= Home; DE=Default Extent; C=Coordinate; SB= Scale Bar; RMO= Reset Map Orientation; ML=My location); *Data Layer Management* (AT=Attribute Table; PY= Polygons; PO= Points; LN=Lines; F=Filters; LL= Layer List; P= Painels); *Editing* (M=Markers; MD= Measure distance; MA=Measure Area; D= Draw); *Interaction* (Z= Zoom; PT=Panning Tool; SE=Search, PR=Print; SH=Share; DW=Download; U=Upload).

In the listing of datasets related to Smart Berth, they generally include the location of terminals, mooring posts, berths, crane locations, as well as nautical and navigation information (Table 2).

Table 2. Summary of the main datasets related to Smart Berth.

Ports	Land Facilities	Nautical or Navigation Information
Anchorange	Berthing, terminals.	-
Mobile	Berthing, terminals, pier, road, and railways networks.	Channels, draft symbols.
Oakland	Terminal areas, cranes, road and railway network, harbors.	Channels, turning basin areas.
Gothenburg	Berthing, road network, terminals, harbors.	Maritime routes, endpoints of service lines.
Montreal	Terminals, road and rail networks, gantry cranes, mobile cranes, container loaders.	Vessel information (Vessel technical sheet (VTS) and Scale Details (SD)), lighthouses.
Paraná	Roads, street, and railway networks, terminals, cranes, storages, gates, trucks traffic, mooring infrastructure.	Vessel information (VTS and SD).
Itaqui	Berthing, terminals, gates.	Vessel information (VTS and SD).
Newcastle	Berthing, terminals, road network.	-
Fremantle	Berthing, terminals, jetties, gates.	-

Hamburg	Berthing, terminals, and road networks.	Vessel information (VTS and SD).
NSW	Berthing, terminals, road, and rail network.	-
Maryland	Berthing, port areas waterfront facilities, cranes, transit sheds, grain elevators, docking, storage facilities.	Navigation history (1990).
Rotterdam	Berthing, terminals, mooring infrastructure, traffic separation system, harbors.	Entrance angle into the port basin; kilometer markers, port basin width, geographic direction symbols, navigation AIDs, waterway lines and areas, pilot station, lighthouses.
Tampa Bay	Berthing, terminals, roads, street, and railway networks, pier.	Bays and channels, water depth symbols.
Panamá	Terminals, roads, and railway networks, cranes, and logistic parks.	Channels description.
Jawaharlal Nehru	Berthing, terminals, jetty, roll on - roll off, road and rail network, fuel station, and truck scanner.	Sea channels description and high and low tides Boundaries.

This survey found that each port has its information sharing policy. All ports displayed datasets on berthing, 93.75% with terminal indication, and 31.25% with crane locations. However, 75% of ports presented vessel information with a description of general vessel type, detailed vessel type, commodities type, and AIS information, for example. While the Port of Gothenburg is developing the Smart Berth system for internal use [45], the Port of Rotterdam, with its system already implemented, stands out for providing detailed nautical and navigation information to external stakeholders [46].

4.Conclusion

The research on GIS platforms aimed to support the development of a collaborative platform aligned with the NEXUS agenda. The study highlights the need for a more integrated and standardized approach to the use of GIS platforms in ports, including the definition of clear information sharing policies. Data selection for visualization varies across ports, reflecting strategic decisions made by each port authority and its stakeholders. Each port has its own information sharing policy. There is no direct relationship between the number of functionalities and the volume of data shared. Despite the importance of visualization platforms for interaction and transparency with the external public, the sharing of strategic information remains a challenge for many ports globally.

Acknowledgments: Content produced within the scope of the Agenda"NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. º 53).

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Observation At the Edge: A Novel Approach to Edge Node Security

Sofia Vaz [1*], Catarina Silva [1], João Paulo Barraca [1], Diogo Gomes [1] and Paulo Salvador [2]

[1] Instituto de Telecomunicações, DETI, Universidade de Aveiro
[2] IEETA, DETI, Universidade de Aveiro
* Correspondence: sofiateixeiravaz@ua.pt

Abstract: Edge Computing has gained popularity in academic and industrial settings. Unlike typical networks where clients communicate with a central cloud server, edge computing moves processing closer to the network edge. Edge computing is able to reduce latency and increase throughput, thus helping 5G networks to meet the envisioned requirements. It has been applied in factory settings, vehicular communication, ports, and other critical systems. One issue is that this distributed operation strategy can hinder secure operation, making it harder to detect malicious nodes or software. The solution proposed in this work aims to address this by adding observability capabilities to orchestrated hosts, without impacting node operation. The solution is highly customizable to enforce observability of key actions, according to the operator security policies. Preliminary results show the solution has a small impact regarding resource use.

Keywords: 5G; Zero Trust; Edge Computing, Microservices

1.Background/ Introduction

Edge computing improves current cloud systems by enabling computation geographically closer to end-users. This distributed approach, in contrast to traditional cloud-centric models [1], empowers edge devices to process tasks autonomously, and together with higher proximity, lead to significant advantages in terms of latency, throughput, and power consumption [2, 3]. The benefits have fostered a multitude of use cases across diverse domains, including real-time harbor surveillance [3], high-efficiency factory automation [4], and latency-critical healthcare applications [5–8]. Furthermore, edge computing's suitability extends to non-critical applications demanding low latency and distributed processing, such as augmented reality [9] and sensor networks [10].

The distributed nature of edge computing, over many small points of presence, also introduces security challenges. The physical and logical dispersion of computational resources diminishes centralized control and visibility, rendering the system susceptible to malicious attacks[11], and to their maintenance without detection. Another problem, this time regarding orchestrated edge nodes, is the typical lack of a physical border, as it creates an easy entry point for threat actors. Moreover, the direct communication between software components decreases observability, as traditional firewalls and network controls are harder to deploy. Then, there is the question of microservices from third parties. They are typically developed by internet service and solution providers, external to the network operator, raising the issues of running external code, which are difficult to assess. The opacity of typical edge architectures emboldens all these problems.

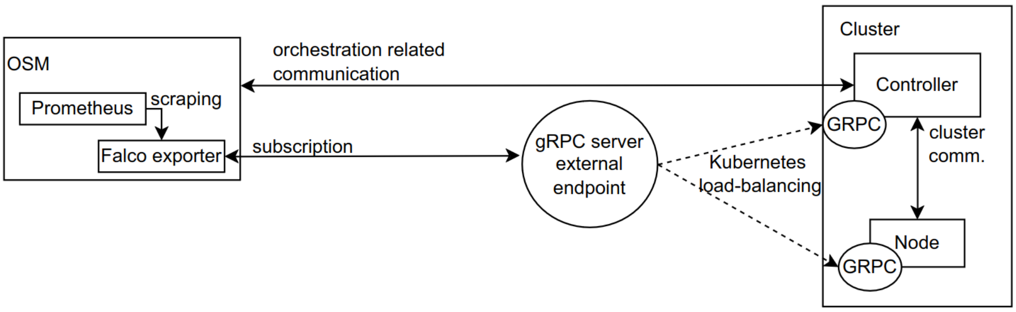
Most existing edge computing security solutions either leverage monitoring [12], which proves to be lacking in the case of a more sophisticated attack [13], or use cloud solutions that, by design, will never fully cater to edge environments [14]. Current work proposes a behavior-based approach in which dangerous actions will result in alerts to overseeing solutions. Thus, an administrator can conclusively determine what actions are taking place instead of relying on metrics and reverse engineering potential attacks from performance variations.

2. Materials and Methods

The current representative scenario considers a proof of concept with an application running on a typical orchestrated host, at an edge point of presence. We address a 5G Multi-access Edge Computing stack, but the work is valid for generic orchestrated environments. The approach considers that operators set policies defining the adequate behavior for applications hosted. Active controls, such as WAFs, firewalls and ACLs can be in place as a way to enforce these policies. Because controls mostly address known methods and tactics, it is still relevant to detect violation attempts, or actions that take place because a threat actor was able to circumvent the existing controls. These actions will make the application behavior depart from baselines, which can be used to create indicators and alerts. Our solution maps policies to rules, generates alerts based on the rules provided and outputs them to a security solution. The observation ability of the solution should be extensive, with the capability to inspect every action that takes place, including network traffic, internal communications between components, or even actions that take place under the scope of the interface between the application and the kernel (syscalls). These are of particular relevance as they provide a view over local escalation attempts, or over an exploit compromising an existing vulnerable application.

The architecture for the proof of concept is presented in Figure 1. As depicted, there are three main blocks – the orchestrator, the cluster in edge hosts, and the security related stack. The orchestrator block comprises the solutions that are responsible for distributing edge applications to hosts in a cluster, according to the rich deployment rules set in their deployment description. Typical solutions for this block are found within Open Source MANO (OSM), but others can be considered. The edge node cluster provides computation capabilities, actually running the applications that provide a given edge service. In our work we consider that hosts run a Kubernetes compliant stack connected to a higher layer orchestrator (OSM). OSM will handle Kubernetes based Virtual Network Functions (VNFs), following the lifecycle of a typical VNF on 5G. OSM also orchestrates support functions into the edge hosts, as a way to provide a common, and secure, execution environment. In our proposal, OSM also orchestrates an observability solution, which is able to take in consideration selected rules, and track the behavior of the remaining applications. We propose the use of Falco, a well known observability solution, exporting data to a centralized Security Information and Event Management (SIEM) solution. With an exporter component in place, it is possible to get important information regarding the application behavior, and assess the current security posture of all nodes and applications in the cluster. In the current implementation, as this work focuses on observability, we output alerts to a Prometheus instance, and view alerts using Grafana. On a real world deployment, alerts should be sent to a SIEM solution, enabling further processing and higher level alerts.

Figure 1: Solution architecture



The solution proposed is highly flexible, allowing observation of a wide range of actions, which are deemed relevant to detect violation of the pre-existing security policy.

Some rules are almost universal, and relevant regardless of the system's application, being proposed by Falco. These were instantiated in the current proof-of-concept, as they provide a baseline to assess the minimum impact of the solution. For example, accessing, reading, or changing configuration files is an important action to monitor. This can represent typical behavior in systems; however, it is also a signal for severe security problems, especially in a Kubernetes environment, where configurations and secrets are provided through ConfigMaps and Secrets. Another obvious monitored behavior is the connection to suspicious third-party hosts. However, it is crucial to acknowledge that this represents only a portion of the complete ruleset. Depending on the specific system and policy, additional rules should be warranted. For instance, in a port setting, hosts are expected to operate with highly specific peripherals and services, and it might be prudent to alert for any irregular behavior related to these endpoints. While no security solution is universally applicable, our solution's customizable nature ensures its utility across a broad range of edge computing environments.

There are two implementations—a single-node (SN) cluster and a cluster with multiple nodes (MN). The two implementations are vital, as they allow us to test the observation system's extensibility under different operational environments.

3. Results

This work involves two implementations of the proposed solution. The first implementation is a single-node (SN) configuration where the monitored cluster comprises a single node, the cluster controller. This controller is a virtual machine (VM) with 8GiB RAM, 4 CPU cores, 64GiB memory, and running Ubuntu 20.04.4.

To evaluate the system's behavior when monitoring multiple machines, a multi-node (MN) implementation was necessary. In this case, the monitored cluster includes a controller and a worker node. The controller has the same specifications as in the SN implementation, while the worker is a bare-metal machine with 16GB RAM, 8 CPU cores, 64GB memory, and running Debian 11.

Regarding results, both implementations are running the observation solution with the same ruleset, making results directly comparable. The ruleset in place is the one created for the current solution, which includes custom and default Falco rules that, to our understanding, will fit most environments.

In terms of the SN implementation, baseline values were measured 1296 times, and runtime values were measured 1363 times. It was found that running the solution impacted the cluster controller by using an additional 69MiB of memory. CPU usage went from 1.6% to 3.35%. This demonstrates that the solution is lightweight when monitoring one node.

For the multi-node implementation, regarding the controller, baseline values were measured 1824 times, and running values were measured 2371 times. The worker's baseline values were measured 5268 times, and running values were measured 1906 times. The controller's memory usage increased by 51MiB. CPU usage rose from 1.6% to 4.3%. The additional node's memory usage increased by 322MiB, likely due to multiple connections by the falco-exporter. When redundant falco-exporter subscriptions were removed in a test run, the memory increase was 70MiB, though this did not allow full functionality. CPU usage on the additional node increased from 0.42% to 0.84%, suggesting minimal impact.

The deployment time for the SN system is 36.95 seconds (deployed 816 times), while for the multi-node system, it is 47 seconds (measured 376 times). Although adding nodes seemingly increases deployment time, the difference is minor and not concerning, especially when taking into account that the difference in time may be due to network latency, as the worker is in a different network and other connections clearly take longer. None of the deployments failed.

In terms of fault tolerance, both single-node and multi-node implementations generated thousands of alerts, all correctly exported to Prometheus without any loss or delay. The system remains resilient even under high alert volumes.

Regarding usability, alerts contain detailed data, including generation time, the Falco instance that generated it, and specific details such as the container, user, or command involved. Rules can be defined using simple syntax similar to Python, requiring only knowledge of kernel behavior. For example, to alert for camera usage, a rule would monitor access to `/dev/video0`.

This security approach, focusing on kernel-level behavior rather than metrics, is not found in most of the existing state-of-the-art solutions, making direct comparisons challenging.

4. Conclusions

In this paper, we proposed an approach to observe the security posture of applications orchestrated in an edge node. The approach is novel, as few solutions in the state-of-the-art aim to observe edge nodes, especially under the assumptions of orchestrated scenarios such as 5G MEC. The issue is complex, with many interactions, through several layers of orchestration, and the current state-of-the-art reflects this. Our solution integrates with existing orchestration stacks, allowing an infrastructure provider to carefully observe the applications deployed to their environment with great detail. The solution is able to observe internal and external interactions, including low level file access, triggering alerts that are dispatched to an external system. We demonstrate the feasibility and applicability of the solution in two relevant scenarios, and show that the impact to system performance is minimal. At the same time, we demonstrate that observability increases, as alerts can be analyzed and triaged in external SIEM systems.

In future work, it would be interesting to block actions from happening and even create rules automatically, as is currently done with EDRs. An alarming issue with current work is the lack of gRPC server authentication, which can be an interesting line of future work. Moreover, further testing with a larger number of nodes is vital, as current testing is limited.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação– Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project nº 53).

Conflicts of Interest: The authors declare no conflicts of interest.

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A Container Transport Network Digital Twin to promote Sustainable Transport Practices: Concept Proof

Pedro Costa [1,*], António Amaral [2,3], Raquel Pereira [4], Carlos Batista [5], Mariana Gonçalves [6] and João Lemos Nabais [7,*]

1 Instituto Politécnico de Setúbal, Business School, Setúbal, Portugal; pedro.costa@esce.ips.pt;
2 School of Engineering, Polytechnic Institute of Porto, Mechanics Engineering Department, Rua Dr. António Bernardino de Almeida, 431, Porto, 4249-015, Portugal; sal@isep.ipp.pt;
3 INESC TEC - Institute for Systems and Computer Engineering, Technology and Science, Rua Dr. Roberto Frias, Porto, 4200-465, Portugal; antonio.m.amaral@inesctec.pt;
4 Instituto Politécnico de Setúbal, Management and Economy Department, Setúbal, Portugal; raquel.pereira@esce.ips.pt;
5 Instituto Politécnico de Setúbal, Marketing and Logistics Department, Setúbal, Portugal carlos.batista@esce.ips.pt;
6 MARLO, Transport and Logistics Consultants, Canaxide, Portugal; marina.goncalves@marlo.pt;
7 IDMEC - Instituto Politécnico de Setúbal, Marketing and Logistics Department, Setúbal, Portugal; joao.nabais@esce.ips.pt
* Correspondence: joao.nabais@esce.ips.pt

Abstract: International trade is increasingly complex and widespread, putting significant strain on Container Transport Networks. These networks are intricate systems comprising multiple players such as cargo owners, freight forwarders, terminal operators, and transport operators, all of whom use available infrastructure to deliver cargo under agreed conditions. Effective cargo assignment, considering terminal storage and transport capacities, is crucial for maintaining a smooth cargo flow and supporting sustainable transport modalities. However, conflicting objectives and unforeseen events, such as adverse weather conditions, can lead to congestion and delays, impacting the overall Container Transport Network performance. This study proposes a Digital Twin to capture the dynamics of the Container Transport Network. The proposed Digital Twin provides a real-time virtual representation of the operations of a Container Transport Network and uses a holistic approach to capture the primary characteristics of the transport network, storage (potential), and movement (flow) of containers. By integrating operational data, logistical information, and environmental parameters, the platform aims to offer valuable insights to optimize operational efficiency and address specific challenges of the existing infrastructure. Illustrative scenarios based on the Atlantic Corridor within the Trans-European Transport Network (T-NET) that are linked to the Port of Sines demonstrate the proof of concept of the Digital Twin proposed.

Keywords: Transport Network; Digital Twin; Sustainability Collaboration, Sines Nexus, TEN-T, Containers

1. Introduction

Freight transportation is a lifeblood of the global economy, enabling the smooth flow of goods and services across borders and driving economic growth. However, this indispensable aspect of international trade brings a series of environmental challenges that cannot be ignored. From greenhouse gas emissions to widespread air pollution and the congestion that plagues urban centers, the environmental footprint of cargo transport is enormous [1] [2]. Looking at these vast challenges, it is becoming increasingly clear that sustainable transport practices are desirable and imperative. The Sustainable Development Goals (SDGs) set out in the 2030 Agenda underline the urgency of the transition to a more sustainable future [3]. By prioritizing sustainable transport practices, we are laying the foundations for a fairer, more prosperous, and equitable future for the next generations. Achieving this goal requires a concerted international effort to adopt policies and implement practices that promote cleaner technologies and investment in alternative transport cooperations. It is essential to adopt innovations in transport collaboration that increase energy efficiency and reduce environmental impact [4]. By doing that, we not only mitigate the adverse effects of freight transport but also pave the way for a future in which economic progress is harmonized with environmental protection.

The definition of Digital Twin has evolved depending on the area of application. However, it is generally accepted that the concept refers to a virtual representation of a real-world system, object or process that is generally used to monitor and perform simulations and /or predict the behavior of these elements in your environment in real time [5]. The concept of Digital Twin, traditionally referenced in the context of a production environment, has expanded to the supply chain as an emerging theme within Industry 4.0, especially since the COVID-19 pandemic, where the potential contribution to supply chain resilience and sustainability was realized. Expanding the concept to the supply chain was only possible with integrating Industry 4.0 components (e.g. Big Data, IoT, etc.) [6].

Freight transport has a very significant impact on energy consumption, so it is important to investigate ways to reduce this impact and make the sector more sustainable. Although there are few studies on adopting the Digital Twin in the field of freight transport, it is generally accepted that the Digital Twin can make a vital contribution by allowing the entire life cycle of the transport system to be monitored [7]. The Digital Twin can act in different application scenarios throughout the supply chain, for example, in container fleet management, monitoring shipment transactions and logistics tracking through IoT sensors deployed in containers that can show data on their location [8]. Despite the interest, the adoption rate in the transport and logistics domain remains low, mainly due to the costs of processing and validating data in centralized scenarios, among other factors [5]

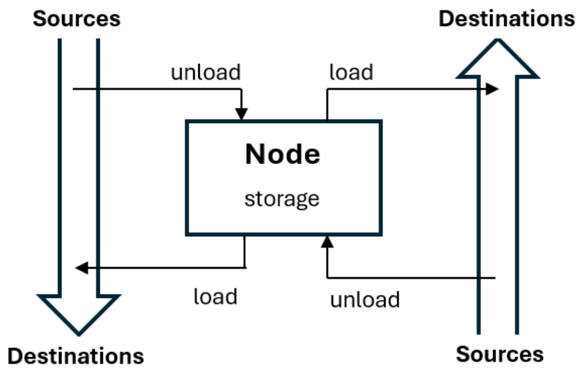
The Digital Twin proposed is built using the Transport Network Library (TNL). The Transport Network Library uses a holistic approach to capture the primary characteristics of the Container Transport Network, storage (potential), and movement (flow) of cargo [9]. The proposed Digital Twin provides a real-time virtual representation of the operations of a Container Transport Network. By integrating operational data, logistical information, and environmental parameters, the platform aims to offer valuable insights to optimize operational efficiency and address specific challenges related to the maximum capacity of intermodal terminals. The library comprises components for facilities (namely distribution centers, warehouses, and factories) and transport connections (namely road, railway, and water transport). The transport network links can link terminal agents with transport agents and allow new agents to be easily added to the existing network. Cargo assignment decisions are executed at terminals, which impacts system performance. Container cargo scenarios based on the Atlantic Corridor within the

Trans-European Transport Network (T-NET) are presented to illustrate the Digital Twin capabilities.

2. Materials and Methods

When addressing a container transportation request from a source node to a destination node, the challenge is to ensure a smooth flow of containers through the different transport network players (merchants, forwarders, terminal managers, shippers, infrastructure owners) towards a more sustainable and reliable transport system. The node model should capture the necessary information to support the Container Transport Network analysis aiming for a more sustainable transport system. A Container Transport Network comprises nodes (particular locations such as deepsea ports, ports, depots, terminals, and hubs) where cargo is handled (loaded and/or unloaded), redirected to the final destination, and may undergo a transport modality switch. The proposed approach to model the dynamics of nodes and connections is based on a flow perspective of containers [10] (Figure 1):

Figure 1. Node and connection interaction in a Container Transport Network.



- **Nodes model:** a storage location of containers of different types that interacts with transport connections to unload or load containers and considers the available transport modalities. The node and transport connections interact at the truck gate, train gate and quayside. Container storage can be handled either in the central yard orin dedicated storage areas by transport modality. At the node, two primary operations are addressed:
    i) Unloading Operations: when a connection arrives brings containers that should be unloaded. As an assumption, the node accepts all the containers other players send. When unexpected container arrives at the terminal, it is considered as a disturbance;
    ii) Loading Operations: when a container load request is assigned to a connection visiting the terminal. This decision is executed locally but can be taken locally or following a centralized approach.
- **Connection model:** refers to the connection between two locations of the Container Transport Network and is represented mainly by a time delay related to the necessary time to move between the two locations (terminals). Connections can visit terminals while approaching the final destination to execute loading or unloading operations. A time schedule and route describe a connection. The connection can be available on a daily basis or have a weekly period, for example, linked to the connection frequency. For the same connection, using the same transport modality, different transport vehicles with different features can be used. The vehicle transport capacity allocated to the connection is also an important characteristic. It, together

with the transport frequency, settles the connection constraints regarding container transport capacity over a specific time interval.

3. Results

The Atlantic Corridor, also designated Freight Corridor No. 4, is a highly significant railway project encompassing several cities and regions along the European Atlantic coast [11]. Its primary objective is to facilitate the transportation of goods, promoting logistical efficiency and competitiveness. Comprising sections of existing and planned railway infrastructure, the Atlantic Corridor connects important cities and ports, including Sines, Lisbon, Madrid, Bilbao, Nantes, and Paris. The aim is to overcome technical and operational barriers, promoting interoperability among the railway systems of the countries involved. In Europe, the Atlantic Corridor plays a crucial role in the trans-European transport network, aiming to enhance connectivity and transport capacity between coastal regions. It also serves as a platform for coordinating investments with the railway infrastructure. Among its strengths is its strategic location, covering key areas of Europe and linking southern Portugal to northern France and Germany. Additionally, it enhances efficiency by facilitating goods transportation, reducing reliance on other modes of transport, and fostering international collaboration through partnerships among Portugal, Spain, France, and Germany, thus promoting cross-border cooperation. Harmonizing systems and standards among countries involved can also be complex. Although the focus is on optimizing existing railway infrastructure, additional investments may be necessary to enhance capacity and quality. In summary, the Atlantic Corridor plays a vital role in European goods transportation, promoting collaboration among nations and improving logistical efficiency along the Atlantic coast (Figure 2).

For illustration purposes, a simplification of the Atlantic Corridor was made considering the transport of containers between Sines (Portugal) and Paris (France). For this purpose, seven nodes (ports and terminals) crossed three countries: Portugal (Sines, Entroncamento), Spain (Madrid, Bilbao, Irún) and France (Le Havre and Paris). Using this simplified network, the container transport between Sines and Paris can be made using different transport configurations: i) only by land transport or ii) by land and water transport. All locations are served by road and railway connections. Maritime connections are available only between Sines, Bilbao, and Le Havre.

The case study was constructed using the Transport Network Library in Matlab (see Figure 3), the nodes are colored in light blue, and the control and planning components are colored in grey. Regarding connections, colors were chosen to emphasize sustainable transport modalities: vessel connections are colored dark green, train connections are colored light green, and truck connections are colored with orange. According to the Container Transport Network design, a sample time of one hour was considered as a period to capture the update of status of the Container Transport Network and the opportunity to update decisions to keep a smooth and sustainable flow of containers.

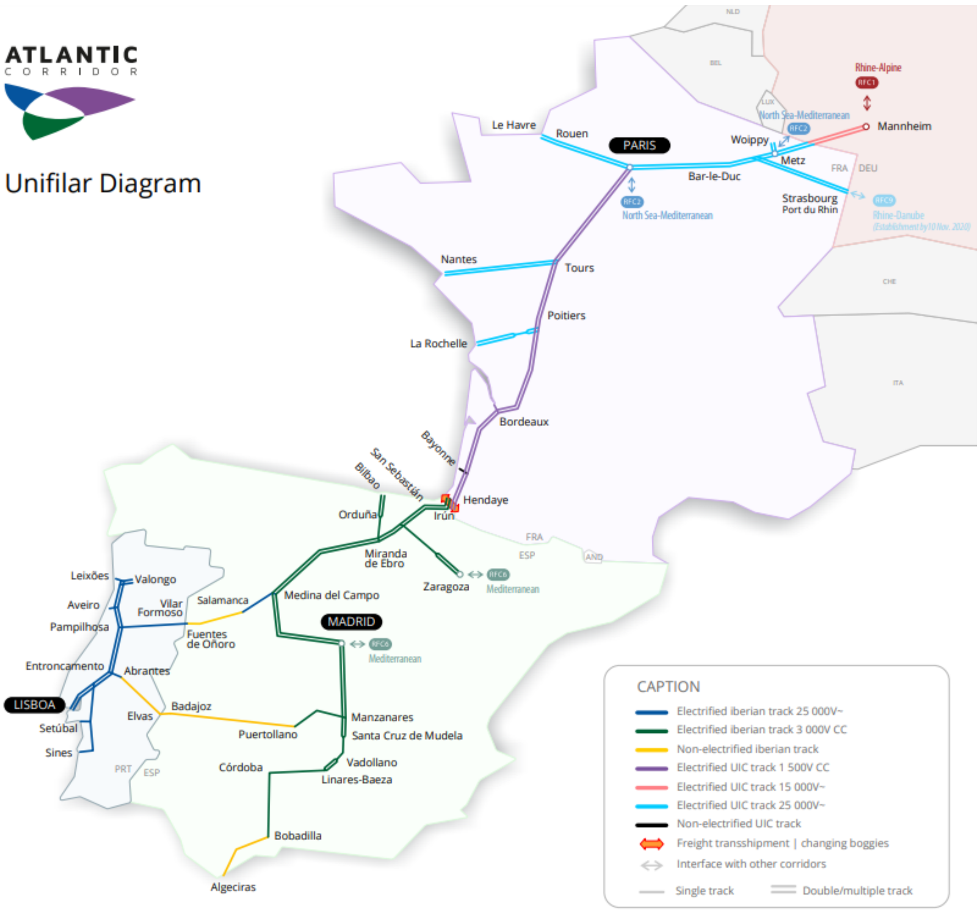


Figure 2. General representation of the Atlantic Corridor [10].

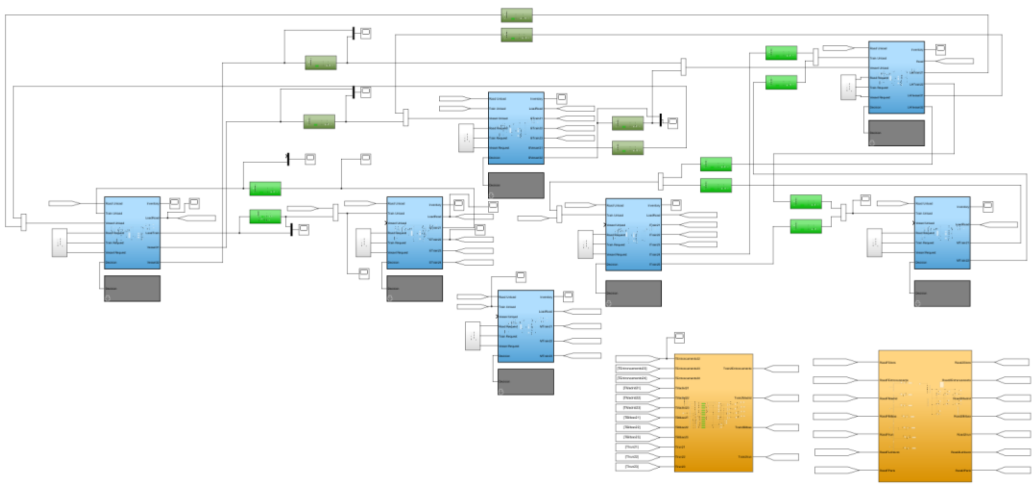


Figure 3. Case study implementation in Matlab.

Regarding the decision-making, the approach was to consider an identical heuristic for all terminals. The heuristic references the desired Transport Modal Split for each terminal and considers the context of each terminal, namely if transport by water is an option [10]. A Transport modal split that favors the use of train modality or vessel modality is more sustainable in order that a container movement is done with lower emission of CO_2. The connections' schedules are available and known to each terminal in advance. The heuristic has access to the amount of containers for each destination parked at the terminal and considering the desired transport modal split, decides the number of containers to load on each connection. The approach is equal in all terminals, and no information exchange is done between terminals. In this sense, the control strategy is distributed, and each player acts alone without sharing information among players. The heuristic implementation allows an automatic allocation of containers to connections visiting the terminal, moving containers towards the final destination using as a guideline the preference for more sustainable transport modalities.

4. Conclusions

The authors followed a based flow approach, using the potential and flow to capture the primary dynamics of a transport network. Containers can be categorized according to the final destination and physical characteristics. The capability to access information regarding the type and location of cargo is fundamental to knowing the state of the Container Transport Network. An heuristic using the desired transport modal split at each terminal as a reference was used to guide the container allocation to connections at each terminal. In this approach, choosing a transport modal split that favors the use of more sustainable transport modalities leads to more sustainable freight transport.

Funding: Content produced within the scope of the Agenda "Nexus – Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n. º53).

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Exploring the use of Digital Twins to optimize berth processes in Commercial Ports

Henrique Calhau [1], Jacinto Estima [2] and Alberto Cardoso [3]

[1] University of Coimbra, CISUC, Department of Informatics Engineering; calhau@student.dei.uc.pt
[2] University of Coimbra, CISUC, Department of Informatics Engineering; estima@dei.uc.pt
[3] University of Coimbra, CISUC, Department of Informatics Engineering; alberto@dei.uc.pt

Abstract: Maritime Ports are sophisticated logistic centers that enable the transportation of goods through sea routes, playing a crucial role in global trade and supply chain coordination. They include tasks like loading and unloading cargo, mooring ships, and allocating resources. Digital Twins (DTs) are simulated models mirroring physical systems, allowing for immediate monitoring, simulation, and enhancement. Commercial Ports are striving for innovative technological solutions to cope with the ever-increasing growth of transport, while at the same time improving their environmental footprint. Although DTs have been successfully integrated in some industries, there is still a lack of cross-domain understanding of what constitutes a DT. Furthermore, the implementation of the DT in complex systems such as the port is still in its infancy. This work aims to fill this gap by building a 2D DT prototype for ports, laying the groundwork for more advanced systems in the future. The developed system includes various features, including the ability to perform visual simulations of berthing and mooring procedures, the integration of Machine Learning (ML) techniques for precise prediction of vessel arrival times, and the capability to compare different berth plans. A DT prototype with these capabilities will help in advancing in the development of more extensive and robust DT systems, aiding in the optimization of port operations as well as improving their energy efficiency.

Keywords: digital twin; port; berth; vessel; machine learning; industry 4.0; internet of things; artificial intelligence.

1. Introduction

The concept of Digital Twin (DT) has been addressed several times given its real application advantages in different scenarios. Authors have attempted and continue to search for ways to better define DT, as knowledge about it increases and questions that still exist become more transparent. One of the first approaches of the DT concept was made in 2002 by the factoring scientist Michael Grieves, in a presentation regarding Product Lifecycle Management in industry. Grieves defines the DT as a collection of virtual information structures that comprehensively represent a physical product, whether it is in the conceptual or material form, comprising its smallest atomic details to its larger geometric aspects. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its DT [1]. In 2012, NASA proposed a widely accepted definition of DT, stating that a DT is a comprehensive simulation of a complex product. It incorporates multiple physics and scales, and utilizes the most accurate physical model, real-time sensor data, historical data, and other relevant information to accurately replicate the behavior and characteristics of its corresponding twin [2]. Figure 1 presents a timeline of some of the most important events regarding the evolution of DTs.

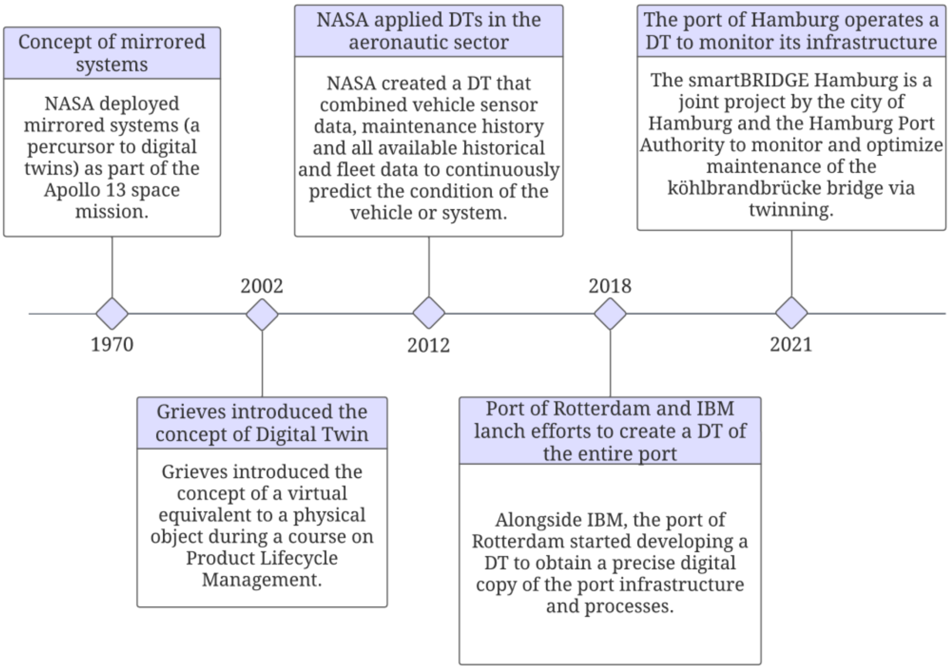


Figure 1. Timeline of historic DT events (adapted from [3]).

A DT contributes to improving processes along the entire value chain, allowing different stages to be seamlessly integrated using a virtual representation of a product or process. This multi-platform technology is built on a significant layer of powerful software and hardware that can include a simulation model, IoT sensors, data analytics and Artificial Intelligence (AI), human-machine interface, Virtual Reality (VR) and/or Augmented Reality (AR), and 3D computer-assisted design [4]. Connecting the physical and virtual via DTs allows improvements in domains such as performance, security, decision-making, risk assessment, time and process optimization [5]. On the other hand, some of the main concerns are related to costs, privacy, integration, reliability and maturity [3, 4]. Although different authors have different views about the properties of a DT and its components, a DT has at least three parts: the physical world, the virtual world, and the bidirectional connection to share data between them [5]. For example, one DT reference architecture model proposed by [7] has four parts: physical, digital, cyber, and communication for data exchange between the three layers. The physical layer defines real attributes, involving objects, assets, products, personnel, equipment, facilities, systems, processes, and surroundings, with sensors and actuators as crucial components. The digital layer collects data in multiple formats, providing digital duplicates of physical entities, while the cyber layer combines cloud processing and storage for a dynamic data model, using scalable technologies.

One industry that can benefit from this type of technology is the Maritime Industry. With the steady growth of maritime transport and global sustainability efforts, ports are under increasing pressure to improve their profitability, environmental friendliness, energy performance and efficiency. Commercial ports fulfil a range of services, as nodes in transportation chains and hubs of economic operations connected to the handling of ships and cargo in the port. As ports handle a multitude of processes performed by a variety of actors in parallel, it is increasingly important to improve the overall view of port processes and identify potential bottlenecks to increase efficiency, safety, and sustainability throughout the port ecosystem [3]. Large ports that have busy container terminals have redefined the container logistic processes and operations through the adoption of different digital technologies such as AI, Blockchain, Cloud Computing, IoT and DTs [8]. Table 1 illustrates multiple examples of important ports adopting DTs for different purposes.

Table 1. Summary of the application of the DT in each port (adapted from [9]).

Location	**DT application**
Rotterdam, Netherlands	Infrastructure and traffic management
Livorno, Italy	Infrastructure and traffic management
Qingdao, China	Equipment and terminal management and overall optimization
Busan, South Korea	Traffic management
Hamburg, Germany	Infrastructure and traffic management

2. Materials and Methods

Design Science Research Methodology (DSRM) was the approach used in the design and creation of this artifact. This methodology comprises six steps: Problem identification and motivation; Definition of the objectives for a solution; Design and development; Demonstration; Evaluation; Communication [10]. This process can (and should) be iterative. Figure 2 intends to demonstrate how the objectives and the design and development phases can be iteratively returned to and adjusted following the evaluation and/or communication.

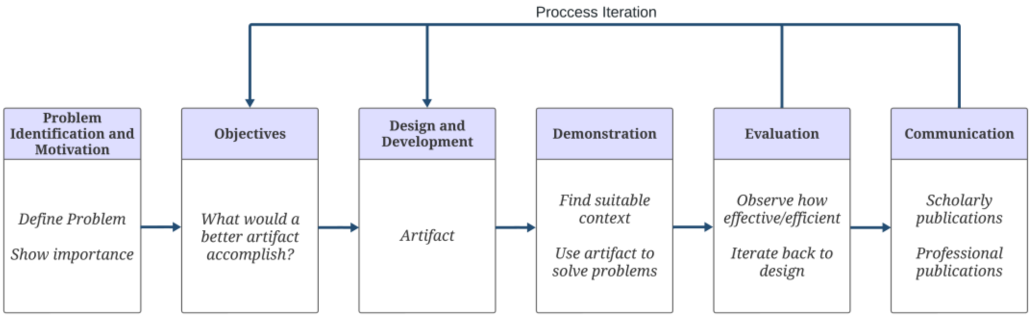


Figure 2. DSRM diagram (adapted from [10]).

The problem is identified, while the Maritime Industry continues to grow and ports are under increasing pressure to improve their efficiency, profitability and sustainability, there is still a lack of innovative solutions for optimization and visualization of port operations. The main objectives of this prototype consist in enabling the user to create, visualize, simulate and compare different berth plans. To meet these objectives, three different components were defined: (i) a 2D Unity environment that allows the user to visualize the port, simulate ships berthing operations and compare different plans; (ii) a Flask API that incorporates an interface and handles the ML models in order to create new berth plans; (iii) a Firebase Realtime Database that allows the user to store the generated berth plans and the details about each performed simulation.

The berth plans are generated using ML models which anticipate the arrival times of vessels and optimize their berth. This is possible through the integration of the ML work performed by Afonso Matoso Magalhães [11]. By creating an interface, the user can input different sets of data to generate different berth plans. These plans can then be visualized and compared within a 2D Unity-based application. The created berth plans and the data related to the simulations are stored in a database for later use. The resulting architecture of this artifact can be seen in Figure 3.

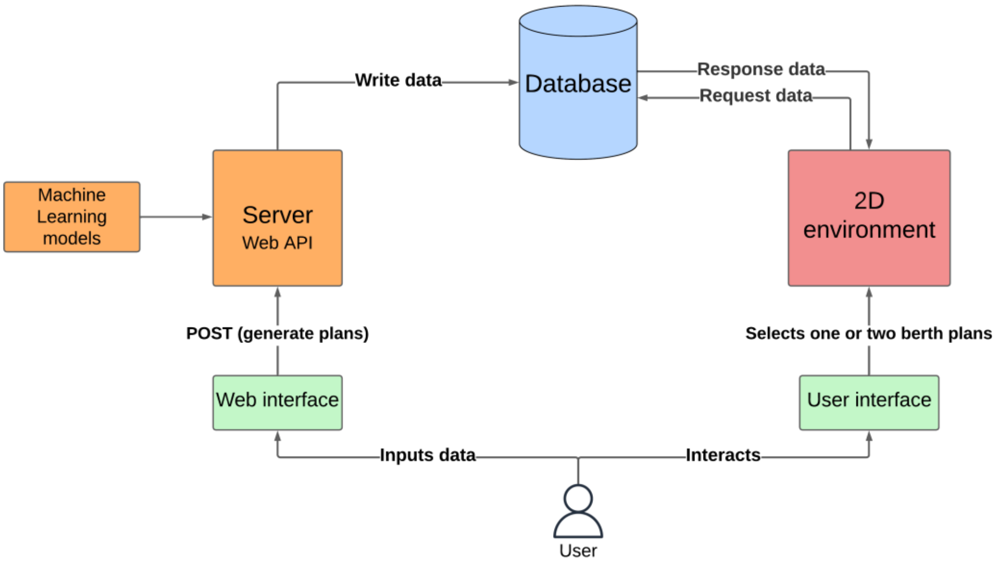


Figure 3. Architecture diagram.

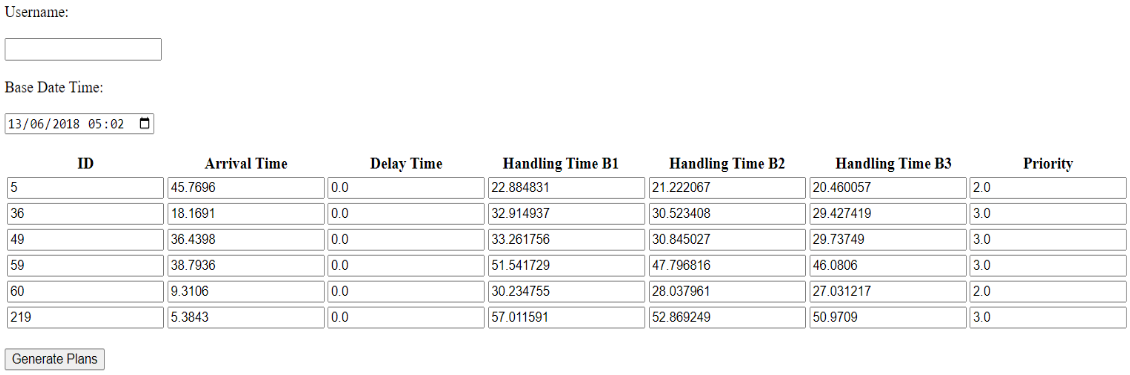
3. Results

The resulting solution includes ML integration, real-time data processing, and interactive simulation environments to create a functional tool for optimizing port operations. The primary proposed functionalities for this artifact were achieved:

- Integration of ML models for berth plan generation;
- Creation of a 2D simulation environment;
- Database integration for efficient data storage and management;
- Demonstration of the prototype's capabilities in simulating various scenarios and comparing berth plans.

3.1. Server API

In the server API, the user has the option to input different sets of data and generate new berth plans using the ML models (Figure 4).



Username:

Base Date Time:

13/06/2018 05:02

ID	Arrival Time	Delay Time	Handling Time B1	Handling Time B2	Handling Time B3	Priority
5	45.7696	0.0	22.884831	21.222067	20.460057	2.0
36	18.1691	0.0	32.914937	30.523408	29.427419	3.0
49	36.4398	0.0	33.261756	30.845027	29.73749	3.0
59	38.7936	0.0	51.541729	47.796816	46.0806	3.0
60	9.3106	0.0	30.234755	28.037961	27.031217	2.0
219	5.3843	0.0	57.011591	52.869249	50.9709	3.0

Generate Plans

Figure 4. Flask API Web interface.

3.2. 2D environment (Unity)

In Unity, if the user selects only one plan, the simulation begins, allowing for the visualization of vessel movement and berthing in the port (Figure 5).

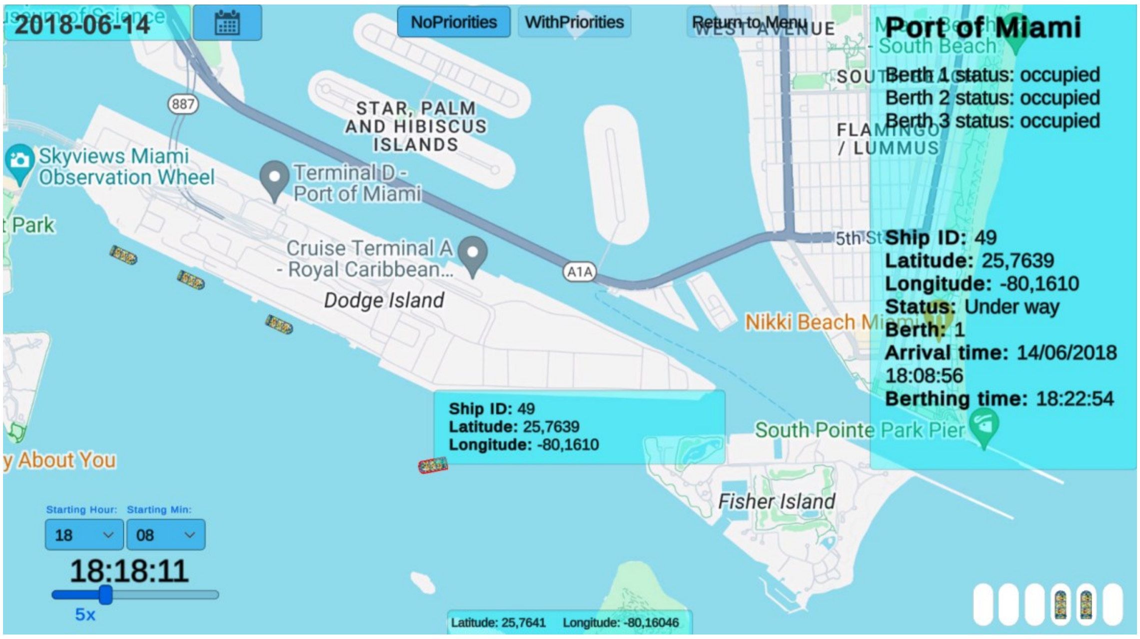


Figure 5. User chooses one berth plan.

If the user chooses two berth plans, a visual comparison of the two plans is displayed including relevant information about each plan (Figure 6).

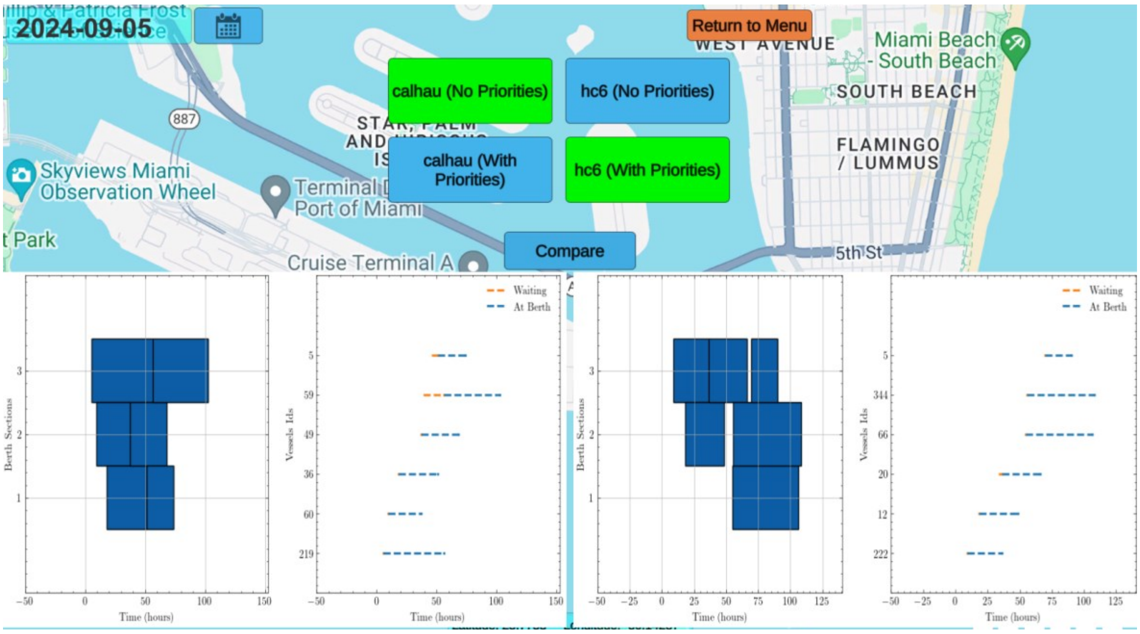


Figure 6. User chooses two berth plans.

4. Discussion

After the development of this artifact, the evaluation was done by conducting a demo with representatives from ESRI, an important stakeholder from the NEXUS program. The demonstration was supported by a series of questions, to get the most valuable feedback and assess the quality of the artifact. Overall, the feedback received was very positive. The participants recognized the value of berth simulation and comparison, as well as the importance of creating new berth plans to optimize berth planning for the possibility of delays.

This research successfully developed a DT prototype designed for the Maritime Industry, specifically addressing the challenges of berth planning in maritime ports. By integrating Machine Learning models with a 2D Unity environment and a robust database, the prototype enables the simulation, comparison, and optimization of different berth plans. The positive feedback from industry experts validates the potential of this solution to enhance port efficiency and decision-making. Future research could explore the integration of additional maritime factors, such as weather conditions and AIS data, to further refine the simulation capabilities. Moreover, expanding the prototype to a 3D environment and incorporating real-time data could significantly enhance its practical application and impact on port operations. While the prototype demonstrates promising results, further development and testing are necessary to fully realize its potential benefits.

Author Contributions: Conceptualization, H.C., J.E. and A.C.; methodology, H.C., J.E. and A.C.; software, H.C.; validation, J.E. and A.C.; formal analysis, J.E. and A.C.; investigation, H.C.; writing—original draft preparation, H.C.; writing—review and editing, H.C., J.E. and A.C.; visualization, H.C.; supervision, J.E. and A.C.; project administration, J.E. and A.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Project "Agenda Mobilizadora Sines Nexus". ref. No. 7113, supported by the Recovery and Resilience Plan (PRR) and by the European Funds Next Generation EU, following Notice No. 02/C05-i01/2022, Component 5 - Capitalization and Business Innovation - Mobilizing Agendas for Business Innovation. It was also funded through national funds by FCT - Fundação para a Ciência e a Tecnologia, I.P., in the framework of the Project UIDB/00326/2020 and UIDP/00326/2020.

Institutional Review Board Statement: Not Applicable

Informed Consent Statement: Not Applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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Open Data and Collaborative Maritime Platforms – a comparative analysis

João Marreiros [1], Bruno Rocha [1], João Graça [2], Cláudio Pinto [3], Vala Ali Rohani [4], Nelson Carriço [5], Tiago Pinho [6] and Ana Mendes [6]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal. E-mail: joao.marreiros@esce.ips.pt; bruno.rocha@esce.ips.pt
[2] MARLO, Lda; joao.graca@marlo.pt
[3] APS – Administração dos Portos de Sines e do Algarve, S.A.; claudio.pinto@apsinesalgarve.pt
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal. vala.ali.rohani@ips.pt
[5] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Tecnologia do Barreiro, Instituto Politécnico de Setúbal, Rua Américo da Silva Marinho, 2839-001 Lavradio, Portugal; nelson.carrico@estbarreiro.ips.pt
[6] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; E-mail: tiago.pinho@esce.ips.pt; ana.mendes@esce.ips.pt
* Correspondence: joao.marreiros@esce.ips.pt

Abstract: The maritime industry is a key player in the global economy, and it is seen as a solution with huge advantages allowing companies to ship big quantities of goods over large distances. As a result, ports have become crucial hubs in handling goods and products, evolving from traditional loading, unloading, and storage points to nerve centers responsible for coordinating the entire supply chain. Open Data Platforms (ODP) play an essential role in the most diverse sectors of activity, whether they are governments or organizations, becoming the fuel for new applications and services. This research aims to thoroughly explore open data and collaborative platforms, focusing specifically on seaports, using a step-by-step process to identify and analyze essential features and frameworks for maritime ODP. The main findings were synthesized to create a comprehensive list of essential features for maritime open data and collaborative platforms, serving as a foundation for our research, incorporating insights from literature, maritime platform analysis, and cross-domain exploration. The results of this research highlight the importance of the ODP in facilitating decision-making and promoting sustainable maritime operations.

Keywords: open data platforms; collaborative platforms; maritime platforms; comparative analysis.

1. Introduction

Maritime transport is a fundamental pillar of global trade, facilitating the transfer of more than 80% of the total volume of goods shipped worldwide[1]. It is predominant due to its ability to move large volumes over long distances, and not necessarily for reducing intermodal operations. While cost is a significant consideration, other advantages include energy efficiency and a reduced environmental impact per unit transported.

However, maritime transport often increases the need for intermodal operations, as goods need to be transported to and from ports [2]. Given the predominance of maritime transport in global trade, ports have evolved into essential interfaces for the handling of goods and products. They have transformed from traditional loading, unloading, and storage facilities into vital hubs responsible for coordinating the entire supply chain [3].

In a society where decisions are becoming increasingly data-driven, open data platforms play an essential role in the most diverse sectors of activity, including both government and organizational activities [4]. They serve as the foundation for developing innovative applications and services [5]. Data is considered open when it is freely available for use, reuse, and distribution, including for commercial purposes [6].

However, previous studies have identified several barriers that must be addressed for open data platforms to fulfill their intended role as fundamental tools. Barriers linked to data quality and standardization, legal constraints, data privacy and security, strategic business issues, technical difficulties, or user literacy end up limiting the true potential of ODP [7].

Thus, the central role that maritime ports play in the world economy also has a huge impact on the links established with thousands of stakeholders throughout their activity, where strong collaboration and clear, transparent communication are highly desirable, if not inevitable [4].

In this context, an Open Data Platform is an online infrastructure specifically designed to facilitate open data discovery, access, and use. ODP unlocks the true potential of open data by making it discoverable and usable.

According to Ali et al. [4], the seven most familiar ODP are introduced as CKAN, DKAN, Socrata, OpenDataSoft, GitHub, Google, and Kaggle, some examples of open-source catalogs that can be used to share open data with the public. This study explains what features ODP typically has, resulting in a comparison framework.

Collaborative efforts within the maritime industry encompass a wide array of initiatives aimed at enhancing efficiency, sustainability, and safety across port operations [8][9]. Furthermore, collaboration extends beyond individual ports to encompass cross-sector partnerships and international cooperation. Initiatives such as data-sharing agreements, joint research projects, and collaborative platforms enable stakeholders to exchange best practices, benchmark performance, and address shared challenges on a global scale [10][11].

Given the growing interest in ODP, the main goal of this research was to explore open data and collaborative platforms, focusing specifically on seaports, using a step-by-step process to identify and analyze essential features and frameworks for maritime open data platforms.

At the end, we present a comprehensive framework for maritime industry stakeholders that offers insights into the landscape of open data and collaborative platforms and outlines strategies for harnessing their potential for innovation and collaboration.

2. Materials and Methods

The first step of this research was to analyze scientific articles that enumerate the reason why ODP fails in three databases: Web of Science, Scopus, and Google Scholar. The strings used were (a) "open data platforms", (b) "open data platforms" AND "limitations", (c) "open data platforms" AND "challenges", and (d) "open data platforms" AND "failures". A total of 530 articles were obtained related to the intended theme. Some selective criteria were applied, like choosing only English written articles or the exclusion of books or book chapters.

After verifying those related to the issues of difficulties or barriers to the use of ODP, a final sample of 34 articles was studied in more detail. This analysis has provided important insights into the characteristics and key factors for the success of that kind of solution.

Next, a comprehensive literature review was conducted, examining scholarly articles and relevant publications about open data and collaborative platforms. This review aims to find key reference materials explaining open data platforms' fundamental characteristics and functionalities. We select articles based on their relevance and significance to our research objectives, one of which proved to be fundamental to understanding the main characteristics found in the most successful platforms [4].

Building on insights from the literature review, an analysis of existing maritime platforms resulted in a list of 39 relevant maritime platforms, which were studied to gain valuable insights into the specific features and frameworks used in the maritime domain. Moreover, 13 other highly relevant platforms in their area of business were also scrutinized to identify cross-domain features that could apply to maritime ODP.

The main findings were summarized to create a comprehensive list of essential features for maritime open data and collaborative platforms, serving as a foundation for the research, incorporating insights from literature, maritime platform analysis, and cross-domain exploration.

3. Main results

To identify characteristics specific to maritime open data platforms (ODP), we analyzed relevant articles retrieved from academic databases during the literature review, as well as websites belonging to ports and port authorities worldwide. Out of 46 websites were studied. Drawing on the main features outlined by A. Mohsan [4], and using the study on the information provided by the websites, the prominent criteria are presented in the framework depicted in the first column of the table shown in Figure 1.

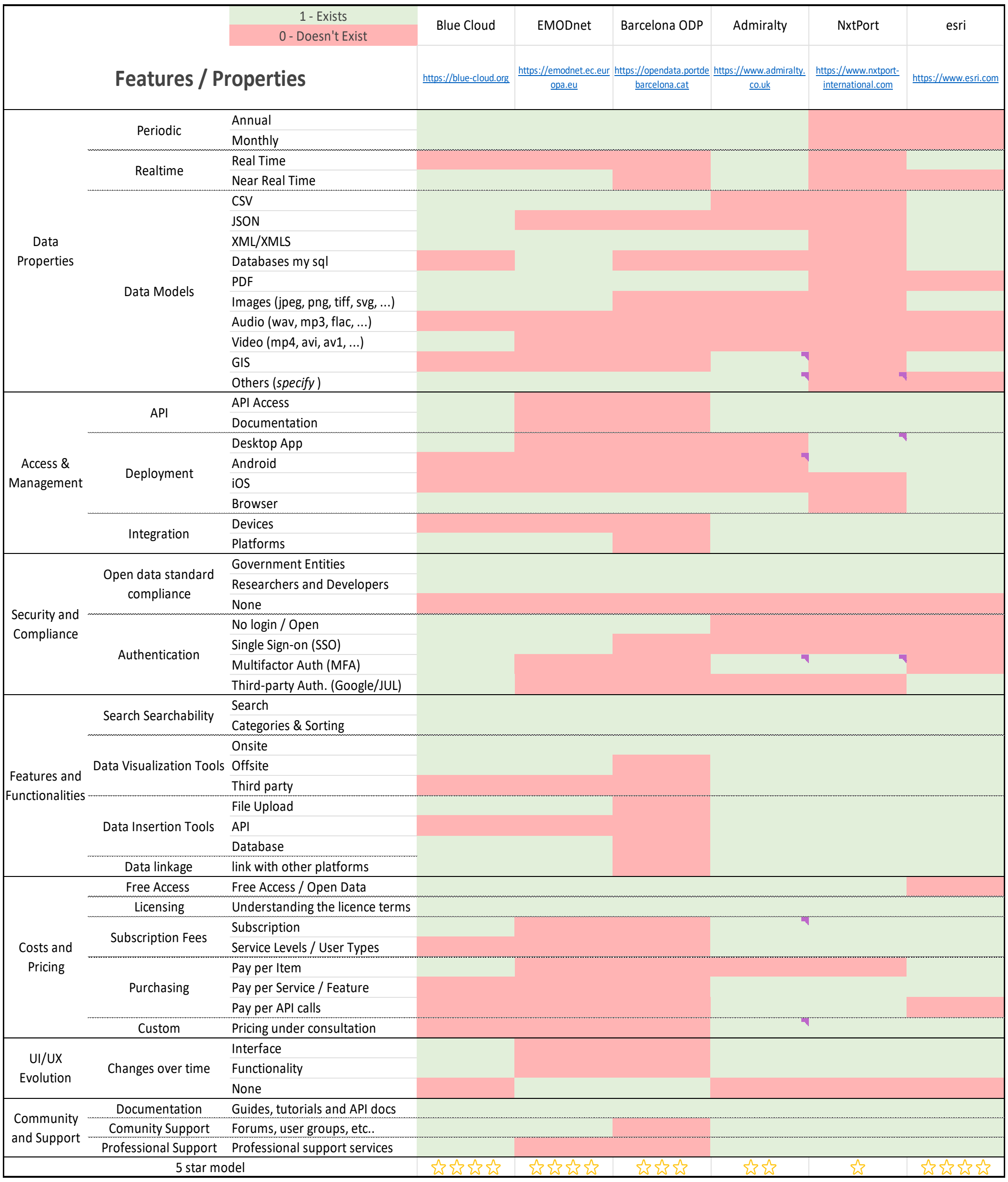

Figure 1. Identified features for Open Data and Collaborative Platforms.

Based on the analysis of the various open data and collaborative platforms, these were the characteristics or functions most common to all of them:

- Community Engagement and Collaboration: Features such as discussion forums, user feedback mechanisms, and collaborative data curation tools, such as version control systems and annotation features, enable users to collaborate directly on datasets.
- User Authentication and Authorization: Secure authentication and authorization mechanisms control access to sensitive or restricted datasets. Authentication should be coupled with integration capabilities with partner platforms to allow for seamless collaboration between different organizations and stakeholders.

- Data Licensing and Usage Policies: Clear licensing and usage policies define how the data can be accessed, used, and shared. Leaves no space for ambiguity.
- Governance and Sustainability: Establishing clear governance structures and sustainability plans ensures the long-term viability of the platform.
- Documentation and Support: Comprehensive documentation and user support services help users navigate the platform. Every interaction on the platform should be thoroughly documented. User support services allow for quick responses and stakeholder satisfaction and can improve the quality of their experience.

When analyzing Maritime ODP, a variety of criteria were considered to assess their effectiveness and suitability for use. These criteria encompass different aspects of the platform's functionality, accessibility, security, and support. Here are some key criteria that we examine:

- Data Properties: evaluated the types and formats of data available on the platform, including whether it provides periodic data updates such as annual or monthly reports and whether the data is available in real-time or near real-time. Additionally, the variety of supported data formats was considered, such as CSV, JSON, XML, databases, images, audio, video, GIS data, etc.
- Access & Management: assessed how users can access and manage the data, including the availability of API and documentation for developers, as well as the deployment and integration options such as desktop applications, mobile apps for Android and iOS, or browser-based access.
- Security and Compliance: examined the platform's adherence to open data standards and compliance with relevant regulations. Authentication methods, including options for single sign-on, multi-factor authentication, or third-party authentication, are also considered to ensure data security and user privacy.
- Features and Functionalities: investigated the platform's search capabilities, data visualization tools, data insertion tools, data linkage with other platforms, and tools for data evaluation to assess the platform's usability and effectiveness in handling and presenting data.
- Costs and Pricing: analyzed the platform's pricing model, including options for free access, licensing terms, subscription fees, and purchasing options such as pay-per-item or pay-per-service [12].
- UI/UX Evolution: using an Internet Archive tool named Wayback Machine [13], tracking changes in the platform's user interface and user experience over time to evaluate its evolution and responsiveness to user feedback and technological advancements.
- Community and Support: considered the availability of documentation such as guides, tutorials, and API documentation, as well as the level of community support through forums and user groups. Professional support services are also considered to assess the platform's overall support infrastructure.
- Performance: To standardize the evaluation of each ODP's performance and thus avoid having several different judgments and opinions, a Google tool called PageSpeed Insight was used [14]. PageSpeed Insight is a platform that analyses and provides suggestions for optimizing web page performance to improve loading speed and user experience. This assessment is made on a scale of 0 to 100, where 0 is poor and 100 is good performance.
- 5-star model: This criterion aims to analyze the five classification levels for the available data on a web platform based on the 5 Stars Model for ODP [15]. This is a framework developed by Tim Berners-Lee, the inventor of the World Wide Web, to

assess the level of openness and accessibility of data on the Web. The model aims to encourage organizations to make data available in a way that maximizes its potential for reuse and interoperability and consists of five progressively more open levels, or "stars," each representing a higher degree of openness and usability.

4. Conclusions

The study conducted on the main criteria and features of the ODP made it possible to see what the principal needs are for them to fulfill their main objectives, which are to facilitate collaboration and access to data, reinforce transparency, and boost growth and decision-making based on shared data. Although it may have some disadvantages, its ability to revolutionize decision-making and promote sustainability highlights its importance in influencing how maritime operations will develop in the future.

By leveraging collective expertise and resources, the maritime industry can overcome barriers to innovation, enhance resilience, and navigate the complexities of an increasingly interconnected and dynamic operating environment.

Future research could examine the most prevalent business models in open data and collaborative platforms.

To complement this study, conducting a survey and analysis on this topic would provide valuable insights, forming a solid foundation for developing solutions tailored to the needs of organizations, communities, or work groups.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).
Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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ENERGY TRANSITION

José Almeida Silva
Renewable Energies Chair of University of Évora
Keynote speaker

Climate change, driven by anthropogenic carbon dioxide (CO_2) emissions, poses significant challenges for all societies. The increase of Earth’s temperature that is already taking place, impacts populations over world, destroys habitats and threatens biodiversity. The challenge of climate change must be tackled in two perspectives, on one hand, its impact must be mitigated by reducing the $C0_2$ global emissions, and on the other hand, adaptation strategies, for the unavoidable impacts of climate change, must be adopted.

Two of the most serious and unavoidable impacts of climate change are the increase of the sea temperature and the consequent rise of the sea level, which according to the IPCC (Intergovernmental Panel on Climate Change) will exacerbate coastal flooding, increase the frequency and severity of extreme sea level events [Pörtner, 2019]. The impacts of such events in coastal infrastructures, such as the Sines port, can be severe. Therefore, the research works here presented by Ngene et al [2], Mata et al [3], respectively describing an automated method to survey wave activity, and systematic approach for long-term monitoring of the water quality, are particularly relevant.

The transition from an energy paradigm based on the use of fossil fuels, to a paradigm where the energy production is centred on the use of low carbon renewable energy sources, such as photovoltaic (PV) or wind energy, is a crucial step to reduce global carbon emissions and mitigate climate change. Carrillo-Galvez et al [4], Lin et al [5], Rezende et al [6] and Ponomarev et al [7] developed different approaches to energy transition in the context of the decarbonization of Sines port. Evaluating the future energy needs is an essential step to plan the energy transition, the work of Carrillo-Galvez et al [4] fits into this agenda, by forecasting the evolution of the electricity demand in ports. The work of Lin et al [5] describes a simulation tool to determine the PV and wind energy potential in logistic port areas, which can serve as a basis for the development of renewable energy projects. Systems based on non-dispatchable energies such as wind and PV, require the use of energy storage devices, the work of Rezende et al [6] addresses this issue by describing an energy management system for ports that considers the use of batteries to store energy. Finally, the work of Ponomarev et al [7] deals with another crucial issue of renewable energy-based energy systems, by presenting an operating tool to manage the electrical grid of Sines port.

Overall, the works included in the Energy Transition chapter, not only address the main aspects of the energy transition in the context of logistic ports but also approach some important aspects of the adaptation to the ongoing climate change.

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Forecasting electricity demand in ports: current trends and future directions

Adrian Carrillo-Galvez [1,*], Felipe do Carmo [1,2], Tiago Soares [1,2], Zenaida Mourão [1,2], Ilia Ponomarev [1], João Araújo [3] and Eduardo Bandeira [3]

[1] Institute for Systems and Computer Engineering Technology and Science – INESCTEC, Porto, Portugal
[2] Faculty of Engineering of the University of Porto – FEUP, Porto, Portugal
[3] Administração dos Portos de Sines e do Algarve, S.A. – APS, Sines, Portugal
* Correspondence: adrian.c.galvez@inesctec.pt

Abstract: In recent years, the increasing interest in the decarbonization of maritime transport, particularly the landside operations taking place at ports, has motivated the development of strategies aiming to improve the environmental performance of ports. Several strategies are envisioned for achieving such a goal, but among them, the electrification of port infrastructure seems to be a future standard within the industry. However, there is still a very limited understanding of ports' electricity consumption patterns and how they can be accurately forecasted. Motivated by this gap, this paper reviews the existing studies related to electricity demand in ports, covering aspects such as real applications, approaches followed and their main limitations. The result of this review shows that, although recognized as fundamental for facing the foreseen electrification processes, forecasting the electricity demand in ports has not been a major concern in industry or academia. In total, only sixteen (16) relevant previous works addressing the problem of electricity forecasting in ports were identified. The results revealed a predominance of simulation-based approaches over data-driven ones and application mainly in container terminals.

Keywords: electricity forecasting; machine learning; ports

1. Introduction

Raising the environmental profile is a priority for European ports policy [1]. To comply with existing and future regulations, ports are experiencing major transformations, aiming to reduce emissions and increase energy efficiency. Among those measures, electrification of infrastructure seems to be a future standard within the industry. According to [2], there is an upward trend towards electrification, which improves energy efficiency, reduces energy costs and greenhouse gas emissions. However, and this motivates our study, there is still a limited understanding of energy consumption patterns and how to accurately forecast the electric demand in ports. Strategies to comprehensively measure and forecast energy consumption by source are not common in ports; and even more, the adopted approaches are very different. However, accurate demand forecasting is crucial for ports. As pointed out in [3], a precise analysis and forecasting of energy consumption not only affects energy security and environment but also provides a useful decision basis for policy makers. In the case of ports, forecasting the current and future electricity demand becomes essential, if not the only way, of effectively carrying out the electrification process. It is worth mentioning that, without using effective forecasting techniques, informed decisions about when to generate or purchase electricity, how much to produce, and how to distribute it cannot be successfully done in ports. This can also help to plan the necessary upgrade of the electrical network in ports (for accommodating the increasing load), reduce costs, improve energy efficiency, ensure a reliable and stable electricity supply and, especially, with the integration of renewable energy sources [4]. Therefore, motivated by the clear importance of the electricity forecast in ports and by the lack of comprehensive studies covering this topic, this work conducted a critical review of the literature. A detailed examination of previous works addressing the forecast of electricity in port is made, focusing on relevant aspects such as: application on real ports, challenges for achieving accurate load forecasting or type of approaches followed. Some important concepts for future research in this field are also highlighted.

2. Materials and Methods

To identify the approaches followed in the literature for forecasting the electricity demand either in ports or individual port terminals, a comprehensive literature review was conducted, as depicted in Figure 1. The keywords "port", "seaport", "port terminal" plus the words ''electricity forecasting'', "short-term load forecasting", "load forecasting"; were used for focusing the search on academic search engines. A total of 16 references were identified, analyzed and grouped according to topics such as the main objective of the forecasting, methodology applied, studied port and publication date.

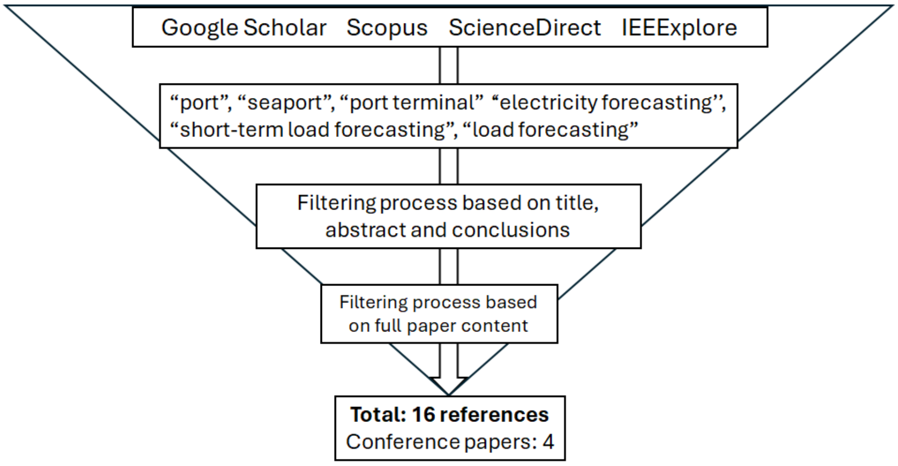

Figure 1. Literature review process.

3. Forecasting demand in ports

It is important to consider that electricity demand in ports differs, even among ports with similar infrastructures. This means that forecasting the electricity consumed in one port, just based on values or methods followed in others, is not always a good option. Therefore, the specificities of each port should be considered when implementing any forecasting technique. We first grouped the analyzed articles into two categories, considering the main approaches followed: data-driven or simulation-based, as presented in Table 1.

Table 1. Load forecasting approaches in ports.

Ref	General approach	Method	Study-case
5	Data-driven	Statistical analysis	Noatum Container Terminal Valencia (Spain)
6		LSTM	Busan New Port (Republic of Korea)
7		feed-forward ANN	Container Terminal Port of Gävle (Sweden)
8		NARX-ANN	Transnet Port Terminal (South Africa)
9		CBR	Container Terminal Altenwerder (Germany)
10		CBR/ feed-forward ANN	Container Terminal (Germany)
11		LSTM-BiLSTM (SVR, GBDT, RF, Nbeats)	Container Terminal (China)
12	Simulation -based	Simulation	Container Terminal Altenwerder (Germany)
13			Port of Tyne (UK)
14			Container Terminals at the Port of Singapore and Jurong Port (Singapore)
15			Container Terminal (Southern China)
16			Shekou Container Terminal (China)
17			Chongqing (China)
19			Yangshan Port (China)
19			Ningbo Port (China)
20			-

From Table 1 two key aspects can be highlighted: (i) forecasting the electricity demand in ports does not seem to be sufficiently addressed in the scientific literature; and (ii) most of the research has focused exclusively on container terminals. It is evident that studying the electricity demand in ports has not been a major concern in the scientific community. For instance, in [21], more than 120 technical papers were found and reviewed by the authors when researching only machine learning algorithms for building load prediction. Even the number of review papers they found, 15 during the 2010-2019 period, is already comparable with the total number of papers we found specifically addressing load forecasting in ports. On the other hand, the relative importance of containerized type of cargo has motivated most of the research, not only regarding demand forecasting, to focus exclusively on container terminals. In any case, forecasting electricity demand in container terminals is still a relevant issue, since assets such as electric cranes or reefers are a significant part of the total consumption in an electrified port. However, ports are very different, and the influence of different types of terminals must be considered and further studied.

Another important difference is the main objective pursued in each article, which can be observed in Table 2. One can observe that papers focusing exclusively on accurately forecasting the electricity demand in ports are not common. In most of these papers, this forecast is needed as an intermediary step to achieve the main objective. For instance, in those works related to Energy Management Systems ([14], [17], [18], [19], [20]), the electric demand due to the operation in port is first forecasted. This forecast, as one can observe in Table 1, was mostly obtained through simulation. Then, it is considered for establishing a coordinated optimization strategy of the electric assets of the port. A limitation in these cases is that the forecasting accuracy has not been properly addressed, since the contributions are more related to the mathematical models proposed or the solution algorithms.

Table 2. Main objectives of the identified articles.

Ref	Objective	Year
[5]	Main consumers identification	2019
[12]	Forecast energy demand based on logistical processes	2014
[9]	Short-term Load Forecasting	2016
[10]	Short-term Load Forecasting	2017
[8]	Day-ahead load forecast	2020
[7]	Day-ahead load forecast	2021
[6]	Monthly electric energy consumption forecast	2023
[11]	Short-term Load Forecasting	2023
[16]	Evaluation of emission reduction strategies	2021
[13]	Evaluation of emission reduction strategies	2023
[15]	Hybrid renewable energy system design	2019
[14]	Energy Management System	2021
[17]	Energy Management System	2021
[18]	Energy Management System	2022
[19]	Energy Management System	2024
[20]	Energy Management System	2024

However, the variability observed in the consumption values used by the different authors could be significant:

- Quay cranes' consumption was considered as 6.5 kWh per container movement in [14], in [16] was considered 2.87 kWh for TEU movement, whereas in [20] it is considered a demand of 320 kW whenever they are active.
- The consumption for yard cranes was considered as 2 kWh per container movement in [14], whereas in [20] it is considered a demand of 180 kW whenever they are active.
- On-shore Power Supply (OPS) consumption was considered as 900 kWh for each hour a ship is berthed in [14]; whereas a different approach is followed by [16], considering the rated power of the auxiliary engines of each ship and a load factor.

Considering the limitations and requirements of the identified approaches, we discuss in the next subsection where, in our opinion, attention should be paid. By addressing some of these issues, ports can be more prepared to face their electrification process.

3.1. Future Research Directions

3.1.1. Monitoring infrastructure

Ports will need to improve their monitoring infrastructure, so they become able to fully capture the dynamics of the electric consumption. Knowing where, when and how much is consumed is key for managing the electrical network. When upgrading the monitoring service, special attention should be paid to cover topics, such as:

- <u>Data granularity</u>: having access to the consumption of individual assets, instead of just the aggregated consumption at the terminal level, can help forecasting tasks, even more, when simulation-based approaches are used and individual assets consumption is needed. This granularity should also consider the meter reading frequency: data used for load forecasting may need to be updated more frequently than data used only for billing purposes;

- Data sharing & Data privacy: openly available data is a necessity for testing and improving load forecasting in ports. When privacy might be an issue, appropriate data handling techniques can be used, see [22].

3.1.2. Monitoring infrastructure

Machine Learning based forecasting methods: using machine learning based methods for forecasting the electricity demand in ports requires more attention. Key aspects to consider are:

- Features engineering: although there exists a clear understanding of relevant features affecting the load demand in several sectors (e.g., buildings, cities, etc), port terminals have unique characteristics, making it necessary to first understand which factors influence the most the electricity demand. For instance, features such as vessel types calling to the port, cargo to be (down)loaded, number of reefers on the yard or the number of electric cranes can be relevant.
- Transfer learning: data-based forecasting models require a large amount of training data. Considering that the port will face major transformation processes (e.g., electrification, OPS, e-fuels, etc), it is very likely that historical electric load data might be insufficient for the training process. As highlighted in [23], a feasible alternative to address data scarcity can be transfer learning, which paradigm relies on learn based models on other areas (ports or terminals), referred to as the source domains, with abundant data, and reuse the knowledge learned on the source domains to assist the model learning for an area with a limited amount of data, referred to as the target domain. However, infrastructure differences between the target and the source port should be carefully considered.
- Online machine learning: retraining forecasting models from scratch every time data change is computationally expensive (due for instance to the installation of additional or more efficient equipment in the terminals). An alternative is the use of online models learning from data streams by updating the model as data become available [24].
- Inclusion of all types of terminals: Each type of terminal has unique operational characteristics affecting the load demand and, therefore, the performance of forecasting models developed for other types of ports. Further studies should encompass not only container terminals.
- Development of interpretable models: a downside of machine learning is that forecast users will face non-transparent, and inexplicable models that are difficult to relate to. To mitigate this shortcoming, explainable Artificial Intelligence is being introduced as a measure to get transparency into the model's behaviour and human interpretation [25].
- Models' complexity vs Computational time: A balance between system accuracy/complexity and computational performance is needed. Forecasting techniques to be implemented in ports should be accurate but should not be extremely complex or computationally expensive. In many ports, the personnel dedicated to managing the electrical grid is scarce, and their infrastructure is not necessarily prepared to deal with the implementation of complex algorithms. Therefore, a trade-off between model accuracy and computational performance must be taken into consideration, accounting for the port's activity and requirements.

4. Conclusions

Ports around the world are facing a major transformation process, moving away from fossil fuels and adopting electricity as the main energy vector. To successfully achieve the green transition by port electrification, a main concern is being able to accurately forecast the electricity demand in ports. Knowing how much, where and when electricity is being consumed is critical for lowering operating costs, planning infrastructure improvements, and ensuring a stable electricity supply. However, studies specifically addressing this issue in ports are rare, as we show in this review. Additionally, most of the studies have focused only on container terminals, neglecting completely the influence that other types of terminals might have on the total demand. Although an increasing number of papers have been published lastly, still more research is needed, specifically about the use of machine learning methods. In this review, one can also highlight other future research directions required to improve load forecasting in a port environment, such as features engineering, transfer learning or explainable artificial intelligence methods.

Author Contributions: Conceptualization, A.C.-G.; methodology, A.C.-G., F.C. and T.S.; software, A.C.-G. and F.C.; data curation, F.C.; writing—original draft preparation, A.C.-G., F.C. and T.S.; writing—review and editing, A.C.-G., F.C., T.S., Z.M., I.P., J.A. and E.B. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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ERE – Planning: a simulation tool for renewable energy production

Xumiao Lin [1], Joana Correia [2], Miguel Marques [3], Ana Foles [4], José Silva [4], Luís Fialho [4] and Pedro Horta[4]

1 Wind Energy, INEGI, xlin@inegi.up.pt
2 Renewable Energies Chair, University of Évora, joana.correia@uevora.pt
3 Wind Energy, INEGI, xlin@inegi.up.pt
4 Renewable Energies Chair, University of Évora, anafoles@uevora.pt; jose.silva@uevora.pt; lafialho@uevora.pt; phorta@uevora.pt

Abstract: Climate neutrality by 2050 is one of the European Union´s biggest goals. The maritime trade of goods is the basis of the economy and society sector. Thus, electrification of transport and harbor operations and replacing fossil-based energy with renewable-based are essential. This paper describes a software as a service – EREPT – created to help decision-makers assess the endogenous energy yield potentially available at a desired location. The tool encompasses simulations for solar and wind renewable sources, battery storage systems and is complemented with economic and carbon footprint assessments. To determine the tool's validity, the Porto of Sines was used as a testbed. In total, 8 wind turbine positions and 3 possible PV technologies were selected to assess the wind and solar energy performance, along with economic estimation. For wind energy, Sines could provide around 185 GWh/year of electricity, with an LCOE of 51,7 USD/MWh. Additionally, the evaluated solar energy could bring 6.7 GWh/year of electricity to the energy grid, at 48 USD/MWh. Despite the generality of the estimations, this tool enhances the domestic and industrial energy transition.

Keywords: Logistic platforms; Seaports; Planning tool; Renewable energy, Carbon footprint; Port of Sines

1. Introduction

The European Union aims to achieve climate neutrality by 2050, which means an economy with zero Greenhouse Gas (GHG) emissions [1]. Thus, one of the primary solutions adopted by, not only the European countries but also the rest of the world, is the transition to cleaner and sustainable energy. The replacement of fossil-based energy with a renewable-based can reduce significantly the GHG emissions [2, 3].

As has been known, economic growth and development are, among the other infrastructures, related to maritime ports. Ports act as gateways to trade, having a strategic importance to a nation, since over four-fifths of all world trade is through the high seas [4, 5]. Therefore, with the evolution of seaborne transport, the emissions from shipping and port operations have gained more attention. Marine transportation emissions account for a substantial share of global GHG emissions, reflecting a 9.4% increase since 2012, with further growth anticipated [6, 7]. Considering the importance of maritime trade to international trade, the decarbonization, digitalization of the logistic infrastructures and operational processes are in the center stage of the sustainability contest [8].

Moreover, in parallel with the GHG emissions, reducing fossil fuel usage can also decrease the emissions of other pollutants, such as nitrogen oxides, sulfur dioxide, and particles, which all cause health risks and can significantly affect the air quality in the port city [9]. One of the most promising approaches to reduce port emissions is the

Onshore Power Supply (OPS), which allows ships to turn off the engines while berthed and plug into an onshore power source, and the electricity provided is from a renewable source [10].

The operation of the ports depends a lot on the electricity provided by the inland electric network. The energy demand of ports is huge and various types of energy are required (electricity, diesel, petrol, and liquified gas) [11]. According to [12], ports can be seen as standalone infrastructures with smart and local grids producing electricity from renewable sources. It can be realized by installing photovoltaic (PV) panels inside a port jurisdiction (open space areas, rooftops, carports, and so on), wind turbine generators, or, most recently, wave energy [13].

The produced electricity can be used to supply electric vehicles, berthed vessels, electric devices, such as cargo handling equipment, and other operation processes. Currently, there are a vast example of ports that implemented renewable energy technologies at their installations. shows examples of renewable energy applications in ports.

Figure 1. Examples of some renewable energy applications in the seaports a) Port of Sines (PV energy) [14], b) Port of Antwerp (Concentrated Solar Thermal) [15], c) Tianjin Port (wind energy) [16] and d) Port of Gothenburg (hydrogen) [16].

c)

The global renewable electricity capacity reached a new record in 2023, nearly 510 gigawatts (GW), mostly driven by China´s solar PV market [17]. Solar and wind power are the biggest sources of green electricity. These two technologies can be easily implemented, and their cost has decreased steadily over the years [18]. To achieve maximum energy production, choosing the best location and the most appropriate technology type are the main concerns of the stakeholders.

The present paper introduces a web simulation tool called Endogenous and Renewable Energies Planning Tool – EREPT, using the Port of Sines as the testbed, under the NEXUS Agenda. This agenda was one of the projects included in the “Agendas of Business Innovation” of the Recovery and Resilience Plan (PRR), aiming to digitalize and decarbonize the Port of Sines logistics corridor.

The developed tool allows users to make a preliminary assessment of solar and wind resources, with the conventional and latest technology design existing in the market, complemented with performance analyses, economic and carbonic assessments, and storage simulations. The following section briefly describes the calculation procedures, as well as assumptions implemented in the EREPT.

2. Materials and Methods

As already mentioned, EREPT allows users to estimate the photovoltaic or wind potential of a given area or location. This enables users to compare and evaluate different project scenarios. Along with this functionality, the main assumptions and databases vary for each resource assessment, together with the calculation models applied in the carbon footprint and economic simulations. Those formulations are established by the Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), and the University of Évora. The computational part of the software was developed by ITGEST.

In this section, the tool's main methods, calculation models and databases will be shortly detailed, as well as the main structure and functionalities.

2.1 Input data

Create a project

Firstly, the user has to create a new project, where the name and the facility's annual consumption must be defined.

Location & Type of energy

Afterward, the project location is introduced by drawing a feature on a map, which could be a point, a line, or a polygon, depending on the type of technology to be simulated (solar or wind).

The solar simulation is mainly based on the Photovoltaic Geographical Information System (PVGIS) APIs service. PVGIS is a web-based calculation tool, implemented by the European Commission, that provides solar radiation and PV system performance information [19]. The parameters introduced for each API call were modified depending on the type of PV system: Fixed, Vertical Monofacial or Bifacial Barrier, Rooftop Horizontal or Gable, Floating, Tracking and Carport

The wind simulations were based on the hourly data provided by Copernicus ERA 5 [20] and Global Wind Atlas (GWA) [21]. The wind turbine used in the calculations has a peak power of 7.2MW, one of the most frequent devices on the market. The wind production is calculated by multiplying the number of hours at each average wind speed with the power curve of the wind generator.

2.2 Output data

EREPT provides as output data the monthly solar radiation value for a Typical Meteorological Year (TMY), the annual energy production, and meteorological parameters such as temperature and air pressure. The solar simulation also delivers a summarized table with information related to the peak power, specific production, the optimum inclination angle of the PV modules, and total annual energy production. Besides, typical confidence levels (P50, P75, and P90) are calculated, which are sometimes required for project 'bankability'.

The output data for wind simulation is similar to solar, the tool also delivers the annual energy production, as well as full equivalent load and load factor.

The economic analysis gives the typical indicators of a renewable energy project, such as payback year, Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and Internal Rate of Return (IRR).

Finally, the EREPT brings the carbon footprint simulation, which gives the quantity of GHG (in equivalent CO_2) produced and avoided by different energy consumers of the Port, such as electrical energy of the grid, combustible consumed by vehicles, vessels, or trucks. Here, the user must insert the quantity of each type of energy consumed in his facility by entering the value in the provided template. The **Figure 2** represents the general view of the EREPT functionalities.

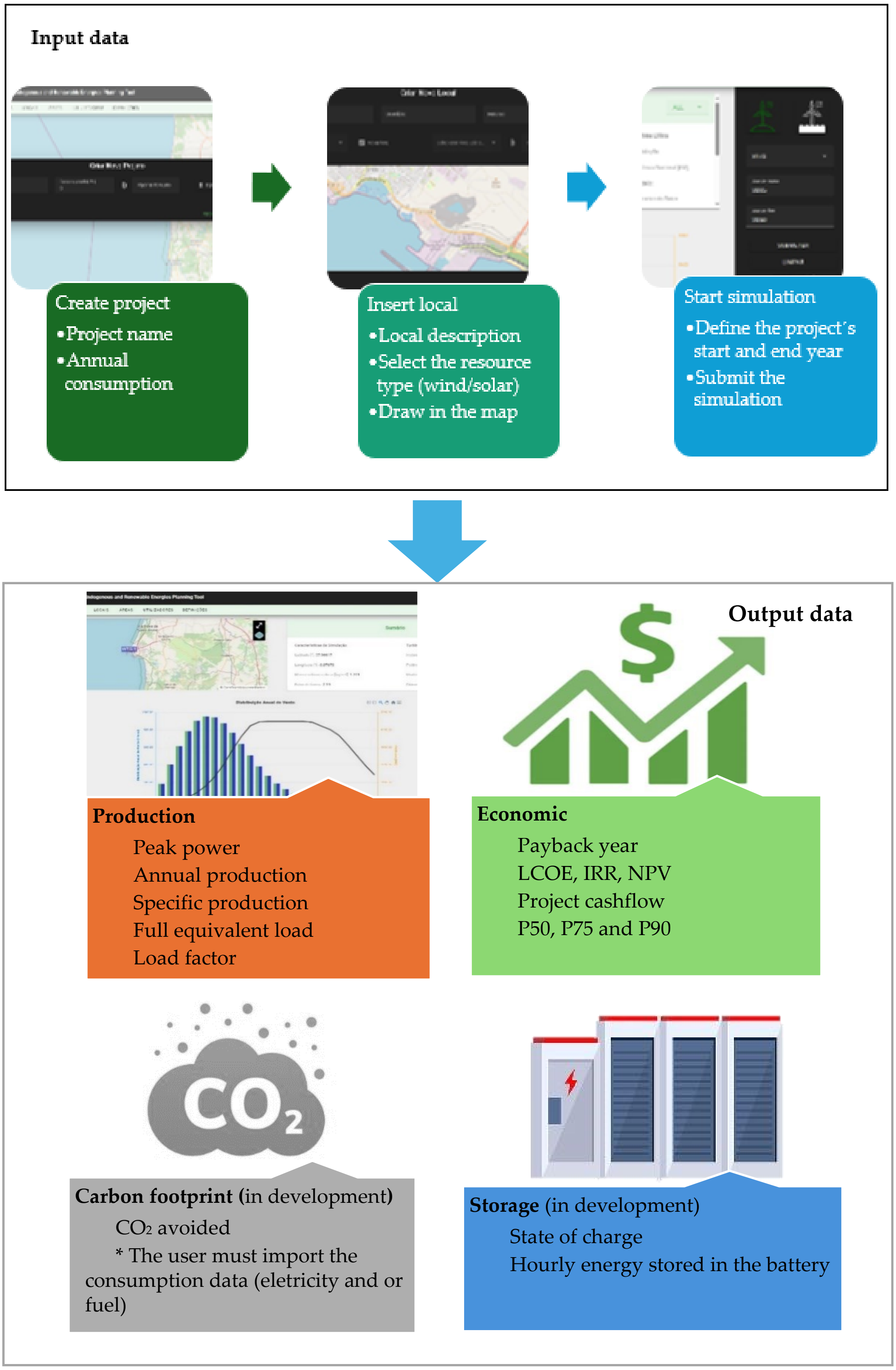

Figure 2. The framework of the EREPT functionalities.

3. Study case

In this section, the endogenous energy resource of the Port of Sines is evaluated using the EREPT. For this simulation exercise, some study areas are assumed to be related to different energy resources and technologies. Meanwhile, the economic assessment is also simulated.

3.1. Port of Sines

The Port of Sines has a privileged location as the westernmost port of Europe, making it one of the most important ports of the Iberian Atlantic and international trade. Its proximity to Lisbon and exceptional land accessibility, such as road and rail, directly link it to the principal's production and consuming market. Furthermore, Sines is the main gateway of Portugal´s energy supply: crude oil and natural gas [22].

3.2. Endogenous energy evaluation

Solar: **Figure** *3* highlights several locations within the Port of Sines Authority (APS) jurisdictional area that were simulated using the tool to assess their PV potential. These locations include system integration on a gable roof, a fixed array on open land, and a bifacial vertical barrier along roads.

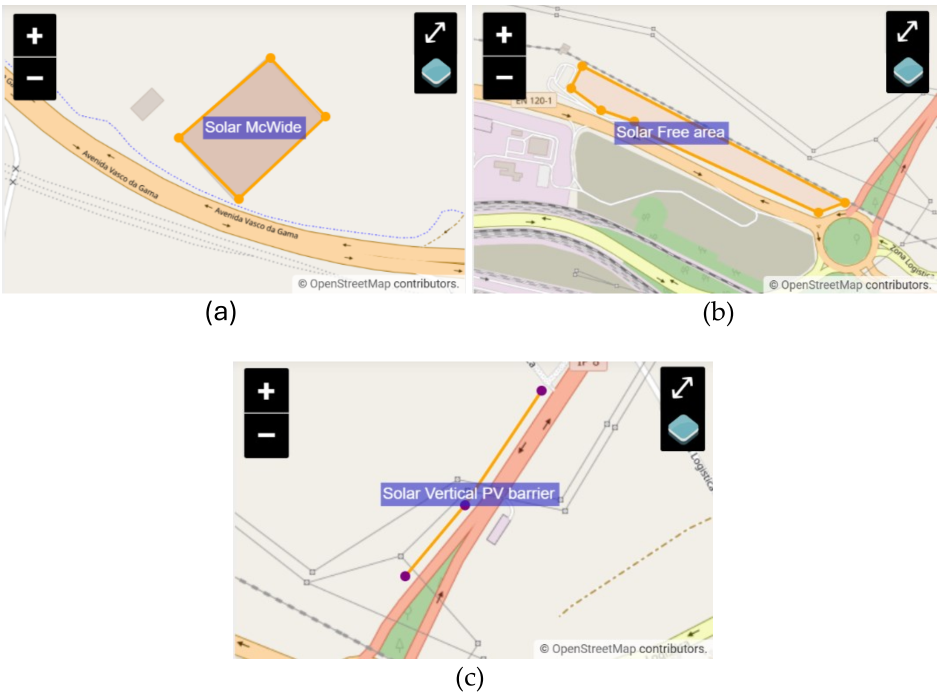

Figure 3. Solar simulation of a PV system on a (a) gable roof, a fixed array on open land (b), and (c) a bifacial vertical barrier along a road, using EREPT.

The following **Table 1** presents the results obtained for the PV potential of the studied locations. These together register a total capacity of around 4.2 MWp and production of 6.7 GWh/year (approximately 25% of the Port of Sines's consumption in 2022).

Table 1. Photovoltaic potential of different areas according to EREPT.

System typology	Dimension [m² or m]	Installed power [kWp]	Energy production [kwh/year]
McWide (Gable roof)	4486 m²	496.7	680307.1
Free area (Fixed PV)	41884 m²	3384.7	5639202.8
Vertical PV barrier (bifacial)	418 m	284.9	412254.0

Regarding to economic estimation, those 3 simulations are expected to have about 8 years of payback, with 5.3 million USD (United States Dollars) of NPV, and a LCOE of 48 USD/MWh.

Wind: For wind energy estimation it was established 8 wind turbine positions in the APS jurisdiction area. The **Figure 4** illustrates each machine´s position. Globally, the wind farm has the ability to install 57.6MWp of wind energy, producing around 185.4 GWh/year of electricity, with an equivalent load factor of 3218 hpc. Those production will be enough to supply the APS energy consumption by 2050.

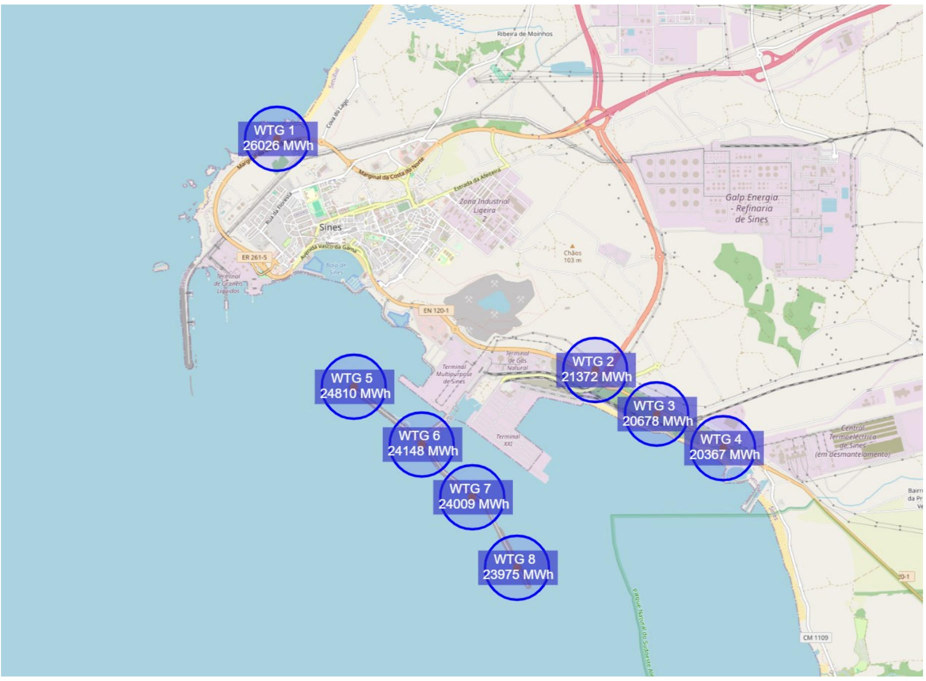

Figure 4. Sines Wind Farm layout

The production performance results of each wind turbine are detailed in **Table 2**.

Table 2. Expected net production of the Sines Wind Farm.

Wind turbine	Annual production [MWh]	Equivalent full load [hpc]
WT 1	26026.4	3615
WT 2	21372.2	2968
WT 3	20678.2	2872
WT 4	20367.2	2829
WT 5	24810.4	3446
WT 6	24147.5	3354

Wind turbine	Annual production [MWh]	Equivalent full load [hpc]
WT 7	24008.6	3335
WT 8	23974.8	3330

The estimation of the APS wind farm project has a payback of 7 years, NVP of approximately 159 million USD, and an LCOE of 51.7 USD/MWh.

Since the Port´s actual needs do not require such a large amount of energy, it is advisable to install turbines in phases, as a gradual increase of energy need is expected.

4. Conclusions

This paper presents an overview of the technical features of EREPT. With this tool, the user can simulate the energy production and performance of solar and wind resources at a desired location. Moreover, the economic and carbon footprint behavior over at least 25 years, which is the general lifetime of a renewable energy project, are also provided.

Under the EREPT simulation, the Port of Sines can be energy self-sufficient by 2050, with the potential to provide electricity to the partners. Both solar and wind energy simulations demonstrate promising estimations. On the one hand wind energy itself can cover all the energy needs of APS. On the other hand, PV projects, due to their installation flexibility, can be easily implemented in ports and cities.

Although the tool is designed for the ports, it can be used and adapted to other user cases in the rest of the world, namely areas attributed to logistics.

The integration of this tool in the decision-making process is crucial for energy transition in the ports. A first overview of local endogenous energy resources gives users an opportunity to know the renewable energy potential of their area, allowing them to perceive whether the implementation of the project would be profitable or not.

Nevertheless, one of the limitations of the tool is the fact that it doesn´t screen the areas with territorial restrictions, such as environmental and patrimonial prohibitions. Since there are multiple territorial restrictions, the user has to have the sensibility to recognize the most suitable area to place their projects.

As future development, the storage component would be assimilated in the EREPT as well as consolidation of carbon footprint assessments. Additional foreseen steps are the consideration of wave energy, detailing offshore installation costs as per substructure type and consideration of territorial restrictions as geographical layers input.

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Energy Management System for Ports Considering Battery Energy Storage Systems

Igor Rezende[1,2,*], Tiago Soares[1,2], Adrian Carrillo-Galvez[1] , Felipe Carmo[1,2], Zenaida Mourão[1,2], João Pedro Araújo[3] and Eduardo Bandeira[3]

1 Institute for Systems and Computer Engineering Technology and Science – INESCTEC, Porto, Portugal; e-mail@e-mail.com
2 Faculty of Engineering of the University of Porto – FEUP, Porto, Portugal
3 Administração dos Portos de Sines e do Algarve, S.A. – APS, Sines, Portugal
*Correspondence: igor.c.abreu@inesctec.pt

Abstract: The increasing demand for the electrification of ports requires the update and development of tools that can improve the operation and management of the electrical system to support the integration of new energy resources. Recently, investments in Energy Storage Systems (ESS), focusing on battery energy storage systems (BESS), gather the opportunity to manage energy consumption flexibly. That is, BESSs may allow the port's system operator to operate the system smoothly, accounting for supply and demand imbalances. In this way, to achieve CO_2 reduction targets, an Energy Management System (EMS) mechanism is needed to manage generation, consumption and the BESS operation. This work proposes an EMS to manage BESS operation in the port of Sines environment. The EMS aims to minimize the total operational cost and indirectly CO_2 emissions of the port. Additionally, the EMS provides a system of hourly recommendations that indicates the feasibility of increasing or decreasing energy consumption to reduce CO_2 emissions. A case study considering data from the port Sines port is applied. Initial results show that the BESS can play a significant role in reducing CO_2 emissions and operating costs.

Keywords: Maritime Port; Battery Energy Storage Systems; Energy Management Systems; Greenhouse Gas Emissions.

1. Introduction

Maritime ports are large consumers of energy and some of the port's logistical activities still depend on the use of fossil fuels, so it can be considered an important player of greenhouse gas emissions [1]. The growing ecological and environmental concern for the decarbonization of economic activities in ports encourages the integration of renewable energy sources and the development of Energy Management System - EMS to properly manage the energy systems [2]. In this way, management of energy consumption and production through flexible resources in ports, such as BESSs, can reduce CO_2 emissions. Therefore, this work proposes an EMS to reduce CO_2 emissions and operating costs in a port environment.

The EMS incorporates data from photovoltaic production and the aggregate energy consumption of the maritime port. Using historical data, the EMS generates forecasts for production and consumption on the day-ahead. To this end, it is proposed an EMS methodology considering the optimal decision of BESS operation setpoints to achieve the optimal balance between financial cost and indirect CO_2 emissions. This decision is communicated directly to the BESS inverter through a setpoint value, enabling precise control of its performance. The port' CO_2 emission parameter considered is the hourly ratio between emission values and energy produced, expressed in kg of CO_2 per kWh. This ratio is obtained through the value of CO_2 emissions expected according to the energy mix for the day-ahead energy market and the corresponding value of energy produced.

The problem considers CO_2 emission prediction, operational cost, BESS operational restrictions and contracted power and minimum energy consumption values as constraints. Historical data of the port of Sines is used to test and validate the EMS model, ultimately reducing CO_2 emissions. A sensitivity analysis is presented to illustrate the impact of the EMS on the port's operating costs.

2. Materials and Methods

This work proposes an EMS model for decarbonising a maritime port, defining the optimal decision regarding the BESS operation considering the vertical demand of the port. Additionally, EMS identify opportunities to reduce greenhouse gas emissions through an hourly recommender mechanism to increase or decrease the port's vertical demand consumption. Therefore, the EMS results are divided into two parts: (i) the optimal BESS operation setpoints determination; and (ii) the consumption recommendation to reduce CO_2 emissions. Thus, the problem is modelled as a Mixed Integer Linear Programming (MILP) optimization problem, as it considers integer variables to model the BESS operation.

For the EMS solution, the mathematical formulation of multi-temporal optimal power dispatch is proposed. The multi-objective function, in the equation (1), describes the minimization of the global operating costs f^{energy} and indirect CO_2 emissions f^{CO_2}, considering the energy cost and weights for CO_2 emissions. This problem also considers market constraints, both energy and reserves market conditions. The energy part of the objective function minimizes the operating cost, in equation (2), (equivalent to maximizing social welfare) by buying E_t^{buy} and selling E_t^{sell} electricity and secondary upward U_t and downward D_t reserves in period t. The power offered $(U_t + D_t)$ to secondary reserve band is multiplied by the respective price band λ_t^B in the time t. The energy activated in the secondary reserve considering the energy ratio activation for upward reserve ϕ_t^U and for downward reserve ϕ_t^D multiplied by price λ_t^U, λ_t^D and the value offered U_t, D_t, respectively. These ratio values, ϕ_t^U and ϕ_t^D, correspond to all power reserve activated by all reserve values contracted in the secondary reserve market for day-ahead, for both directions upward and downward. Equation (3) represents the CO_2 emissions per unit of energy α_t [gCO_2/kWh] in each interval t, which is multiplied by the expected consumption by the port in both markets. In this case, expected consumption is represented by energy buy E_t^{buy}, energy charging in reserve upward $U_t^{ch}\Delta t$ and energy discharging downward $D_t^{ch}\Delta t$ multiplied by the upward/downward reserve market activation ratio ϕ_t^U, ϕ_t^D, respectively.

$$Min\, f = f^{energy} + f^{CO_2} \tag{1}$$

$$f^{energy} = \sum_{t=1}^{T} \left[E_t^{buy}\pi_t^{buy} - E_t^{sell}\pi_t^{sell} - \lambda_t^B(U_t + D_t)\Delta t + (\lambda_t^D\phi_t^D D_t - \lambda_t^U\phi_t^U U_t)\Delta t \right], \quad \forall\, t \in T \tag{2}$$

$$f^{CO_2} = \sum_{t=1}^{T} \left[\alpha_t E_t^{buy} + \alpha_t(\phi_t^U U_t^{ch} + \phi_t^D D_t^{dch})\Delta t\,)\right], \qquad \forall\, t \in T \tag{3}$$

Equation (4) represents the energy netload $E_t^{netload}$ calculation by the difference between energy traded E_t^{buy} and E_t^{sell} in the time t. Likewise, the energy netload values for each interval t is composed of the sum of energy consumed E_t^{load}, the energy of BESS' charging P_t^{ch} and discounting the value of the energy produced by photovoltaic panels E_t^{pv} and BESS' discharging P_t^{dch}, as shown in the equation (5).

$$E_t^{netload} = E_t^{load} - E_t^{pv} + P_t^{ch}\Delta t - P_t^{dch}\Delta t, \qquad \forall\, t \in T \tag{4}$$

$$E_t^{netload} = E_t^{buy} - E_t^{sell}, \qquad \forall\, t\, \in T \tag{5}$$

Constraint (6) defines that the secondary reserve band must be 2/3 for upward U_t and 1/3 for downward D_t, according to the rules of the secondary reserve market in MIBEL [3].

$$U_t = 2D_t, \qquad \forall\, t\, \in T \tag{6}$$

Constraints (7) and (8) define the upward U_t and downward D_t secondary reserve bids, respectively.

$$U_t = U_t^{ch} + U_t^{dch}, \qquad \forall\, t\, \in T \tag{7}$$
$$D_t = D_t^{ch} + D_t^{dch}, \qquad \forall\, t\, \in T \tag{8}$$

The operation of the BESS is defined by constraints (9)-(13). Constraints (9) describe the state-of-charge SoC_{t+1} for the sequence period of t, so at time t+1. The efficiency of charging is defined by η^{ch}, while the discharging efficiency is given by $1/\eta^{dch}$. Therefore, SoC_{t+1} is obtained through the sum of SoC_t for the previous period t and the energy value of charging $\eta^{ch}P_t^{ch}\Delta t$ and discounting energy of discharging $P_t^{dch}\Delta t/\eta^{dch}$. Constraints (10) define SoC_{t+1} limits for minimum value $\underline{SoC}$ and for the maximum value $\underline{SoC}$ of the BESS.

$$SoC_{t+1} = SoC_t + (P_t^{ch}\eta^{ch} - P_t^{dch}/\eta^{dch})\, \Delta t, \forall\, t\, \in T \tag{9}$$
$$\underline{SoC} \leq SoC_{t+1} \leq \underline{SoC}, \forall\, t\, \in T \tag{10}$$

Constraints (11)-(13) set the range of the charging and discharging power. The power spaces variables represent the storage capacity to compensate for the activation of upward U_t^{space} and downward D_t^{space} bands [4]. The limit capacity of BESS charging is defined by the range value of a minimum $\underline{P^{dch}}$ and maximum value $\underline{P^{ch}}$. Similarly, discharging limits are constrained by minimum value for $\underline{P^{dch}}$ and $\underline{P^{dch}}$ for maximum value. The X_t binary variable indicating the charging (1) or discharging (0) mode of BESS.

$$\underline{P^{ch}} \leq P_t^{ch} + D_t^{space} \leq (1 - X_t)\, \underline{P^{ch}} \tag{11}$$
$$\underline{P^{dch}} \leq P_t^{dch} + U_t^{space} \leq X_t\, \underline{P^{dch}} \tag{12}$$
$$P_t^{ch} + P_t^{dch} + U_t^{space} + D_t^{space} \geq 0 \tag{13}$$

The reserve offers are constrained by the upward band limits expressed in (14) for discharging and (15) for charging, while constraints (16) and (17) limit the downward band. Constraints (18) and (19) guarantee that the storage only supplies upward and downward bands if the SoC is within the maximum and minimum limits. Constraints (20)-(22) ensure that the storage has enough capacity to compensate for the activation of upward and downward bands. For that, in the equation (21), Y_t is a binary variable indicating if there is power space for offering upward and downward reserves and M is the parameter with the biggest value to ensure the maximum reserve capacity is offered.

$$0 \leq U_t^{dch} \leq \underline{P^{dch}} - P_t^{dch}, \forall\, t\, \in T \tag{14}$$
$$0 \leq U_t^{ch} \leq P_t^{ch}, \forall\, t\, \in T \tag{15}$$
$$0 \leq D_t^{dch} \leq \underline{P^{ch}} - P_t^{ch}, \forall\, t\, \in T \tag{16}$$
$$0 \leq D_t^{dch} \leq P_t^{dch}, \forall\, t\, \in T \tag{17}$$
$$(U_t^{ch}\eta^{ch} - U_t^{dch}/\eta^{dch})\, \Delta t \leq SoC_{t+1} - \underline{SoC}, \forall\, t\, \in T \tag{18}$$
$$(D_t^{ch}\eta^{ch} - D_t^{dch}/\eta^{dch})\, \Delta t \leq \underline{SoC} - SoC_{t+1}, \forall\, t\, \in T \tag{19}$$
$$U_t^{ch} + U_t^{dch} + D_t^{ch} + D_t^{dch} \leq U_t^{space} + D_t^{space}, \forall\, t\, \in T \tag{20}$$
$$U_t^{ch} + U_t^{dch} + D_t^{ch} + D_t^{dch} \leq Y_t\, M, \forall\, t\, \in T \tag{21}$$
$$U_t^{space} + D_t^{space} \leq (1 - Y_t)M, \forall\, t\, \in T \tag{22}$$

3. Results

3.1. Case characterization

The developed model has been tested and validated using the Port of Sines (Sines, Portugal) data, and the results include a sensitive analysis comparing benchmarking solutions with and without EMS, to assess their relevance.

A flow battery is assumed to store electricity during periods of high renewable production and participate in the secondary and tertiary reserves markets of MIBEL. It is assumed that this BESS has 30 MWh for energy storage capacity, an initial state of charge with 10 MWh, a power capacity of 5 MW and the charging and discharging efficiency of $\eta^{ch} = 0.95$ and $\eta^{dch} = 0.9$, respectively. Electricity prices from the MIBEL market have been used. More precisely, **Error! Reference source not found.** illustrates the price of electricity purchased through the MIBEL day-ahead energy market (red trends), secondary band price (blue trends), and upward/downward activation prices of the secondary reserve market, historical data from a day of 2022.

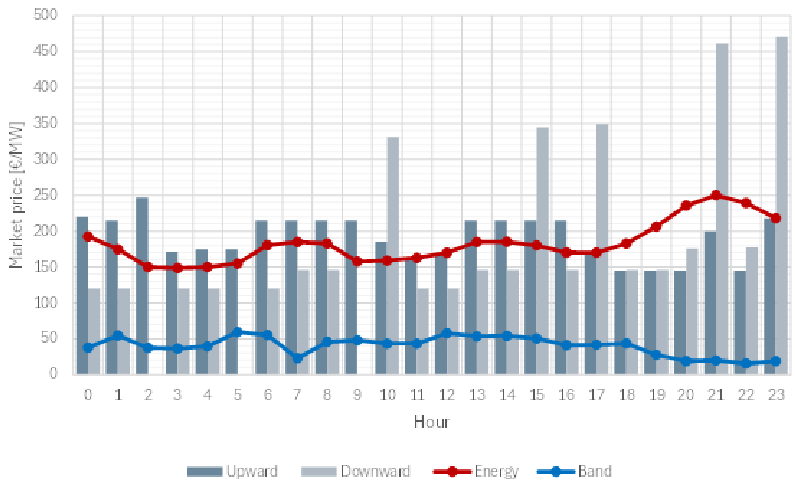


Figure 1. Energy market, band and upward/downward secondary reserve prices from MIBEL for a day in 2022[5].

The data regarding CO_2 emissions forecast is obtained from a data management platform that gathers and stores publicly available data from REN (Portugal) [6] and ENTSO-E Transparency Platform (Europe) multiple times per day [7]. The data features were retrieved from historical records from Portugal, Spain and France. The carbon emission intensity is computed through the emissions that result from the electricity generation required to satisfy its consumption, including the electricity generated in other countries that is being imported. The carbon intensity is forecasted directly using the previously calculated historical carbon intensity as the target for the statistical/machine learning algorithm. The explanatory variables include the observed electricity generation per technology, day-ahead scheduled generation and renewable energy forecasts.

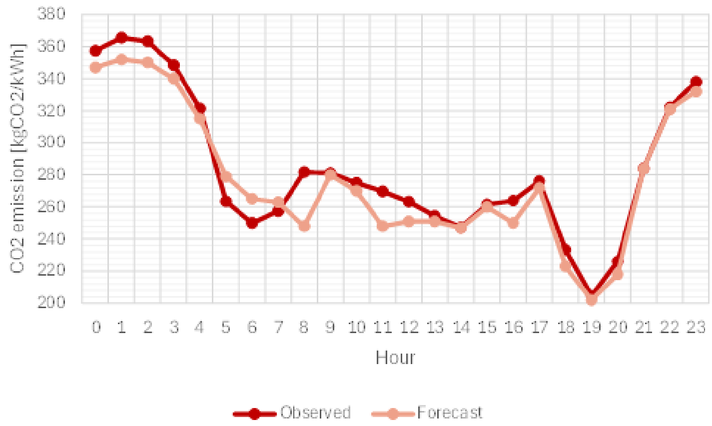


Figure 2. The CO_2 emissions forecast trend and observed data for a day in 2022.

3.2. Results

The result expected by the EMS optimization is used in two actions: (i) determine the operation of the BESS installed in the port unit through the hourly charging or discharging values (these values can be null, which means that it is not feasible to charge or discharge the BESS); and (ii) generate an hourly recommendation system for reducing CO_2 emissions through a Traffic Light (TL) system.

The EMS decision-making results for BESS operation setpoints to achieve the minimization of CO_2 emissions and operating costs of the port are obtained as the use case results. Therefore, by comparing the baseline with these use case results, it is possible to evaluate the impact of using BESS on reducing CO_2 emissions, also at the same time, on the global cost. Historical consumption data for 2022 from the port of Sines is used.

The Figure 3 presents the costs results from the same day in 2022 referenced previously. The financial costs are analysed under four scenarios: (i) Baseline which includes only the energy consumption and PV production, the total cost is 32.86 monetary units (m.u.); (ii) Baseline with BESS incorporating a BESS operating under a simplified strategy that only responds to surplus energy, achieving a total cost of 29.02 m.u.; (iii) EMS without CO2 where the proposed EMS is applied, optimizing only for the lowest operating cost, resulting in gain of 6.77 m.u.; and (iv) EMS with CO2 where the EMS is configured to minimize both financial cost and CO_2 emissions, achieving the gain of 3.20 m.u.

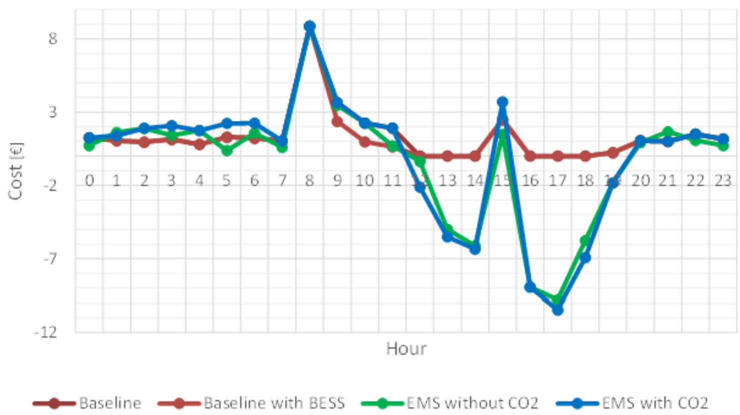
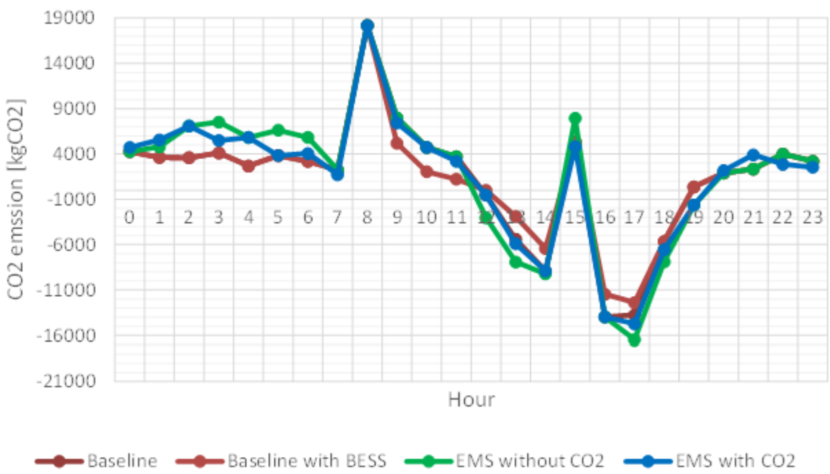


Figure 3. The cost results for a day in 2022.

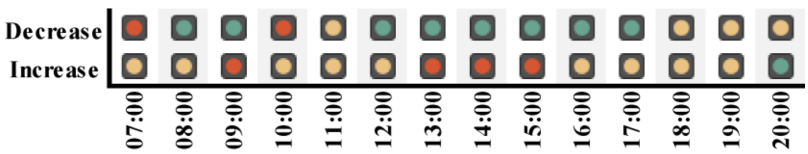
Figure 4 presents the CO_2 emissions outcomes. The scenarios analysed: (i) Baseline resulting in CO_2 emissions of 38,067.83 $kgCO_2/kWh$ for this day; (ii) Baseline with BESS achieving emissions of 32,485.91 $kgCO_2/kWh$; (iii) EMS reducing emissions further to 35,951.08 $kgCO_2/kWh$; and (iv) EMS with CO_2 achieving the lowest emission level of 31,115.60 $kgCO_2/kWh$. These results illustrate that integrating the EMS, especially with an emphasis on CO_2 reduction, can significantly decrease the carbon footprint of port operations. The EMS with CO_2 minimization offers the best outcome, underscoring the system's potential to align financial and environmental goals in a balanced approach to sustainable energy management.

Figure 4. The estimation of CO_2 [$kgCO_2/kWh$] emissions for a day in 2022.



The TL of EMS recommender indicates the green flag as a feasible action and the red flag as an unrecommended action. For each one-hour interval, the actions to increase and decrease consumption at that time are assigned TL evaluations. The assessment of the increase in energy consumption considers the expected consumption profile for the day-ahead added to progressive increases up to the contracted power limit. On the other hand, the reduction in energy consumption is considered a progressive decrease up to the minimum consumption limit pre-defined for the port's activities. An example of an expected result of the EMS recommendation for this day for 2022 is shown in Figure 5, in which the TL for each hour and each direction of consumption, upward and downward, are presented.

Figure 5. The EMS Traffic Light recommender for a day in 2022.



4. Discussion

The EMS' results obtained highlight the advantage of using the EMS to optimize BESS operations in the energy and reserve markets, significantly reducing operational costs and potentially even generating profit. Although prioritizing CO_2 emission reduction can sometimes conflict with cost minimization, as observed in this simulation, the EMS still yields a better outcome than traditional management without EMS intervention. This indicates that the EMS can balance financial and environmental objectives, enhancing both economic and sustainability performance for port operations.

Additionally, the TL recommender provides guidance for operators of other controllable loads, suggesting setpoint adjustments that favor reductions in either cost or CO_2 emissions. This tool enables operators to make informed adjustments that align with the broader goals of financial savings and environmental sustainability.

5. Conclusions

Energy management systems are essential for the green transition of maritime ports. In this way, this work proposes an EMS methodology to minimize operating costs and CO_2 emissions simultaneously, accounting for the BESS operation. An important conclusion is that, even though the method can provide the best operational consumption to reduce CO_2 emissions of the port through the optimized activation of the BESS, the EMS can provide more impact of emissions reduction with the recommendation system.

Author Contributions: Conceptualization, I.R. and T.S.; methodology, I.R. and T.S.; software, I.R.; validation, I.R. and T.S.; writing—original draft preparation, I.R.; writing—review and editing, I.R., T.S., A.G., F.C., Z.M., J.A. and E.B.; supervision, T.S. and Z.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação –Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. .º 53).

Conflicts of Interest: The authors declare no conflicts of interest.

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Technical Grid Operating Tool for Application at the Port of Sines

Ilia Ponomarev [1,*], Tiago Soares [1,2], Adrian Carrillo-Galvez [1], Micael Simões [1], Felipe do Carmo [1,2], Zenaida Mourão [1,2], João Araújo [3] and Eduardo Bandeira [3]

[1] Institute for Systems and Computer Engineering Technology and Science – INESCTEC, Porto, Portugal
[2] Faculty of Engineering of the University of Porto – FEUP, Porto, Portugal
[3] Administração dos Portos de Sines e do Algarve, S.A. – APS, Sines, Portugal
* Correspondence: Ilia.Ponomarev@inesctec.pt

Abstract: Due to environmental challenges, greening seaports became one of the main trends of maritime transportation industry. This transformative shift is primarily driven by initiatives focused on electrifying port operations and integrating renewable energy sources (RESs) into port electrical grids.
To address these challenges, specialized grid operating tools are essential. This paper presents an extended abstract demonstrating the performance of a developed technical grid operating tool in the context of the Port of Sines. The tool's primary objectives are to optimize operational costs and ensure grid stability despite the complexities introduced by electrification and RES integration.
The results section includes small-scale validation of the grid operating tool and comparison showcases how the tool effectively manages grid operations. The project underscores the importance of advanced grid management tools in achieving environmental sustainability goals in maritime logistics.

Keywords: grid operating tool; maritime port; renewable energy sources

1. Introduction

Maritime transportation is a large contributor to greenhouse gas GHG emission that accounts for 3%-5% of the total global GHG emissions [1]. The rapid growth of international shipping leads to increasing port activities and exacerbates the contribution to global warming [2].

Addressing the environmental impact of ports is a key driver for initiatives aimed at greening seaports. Decarbonization efforts focus on electrifying port assets and integrating renewable energy sources (RESs) into the electrical grid [3]. These changes transform the port's electrical grid into an active distribution network (ADN). In such networks, high variability in voltages and power flows can occur, and during periods of high load growth, the grid may face challenges in adhering to grid code constraints. Therefore, there is a need for specialized tools to maintain grid parameters within predefined limits [4], [5].

Moreover, active distribution networks in ports present opportunities for optimizing operational costs. By leveraging advanced grid operating tools, ports can enhance their efficiency and reduce costs while maintaining reliable and stable grid operations.

The purpose of this extended abstract is to demonstrate the performance of a developed technical grid operating tool in the context of Port of Sines. This tool aims to optimize the operational cost and ensure that grid parameters remain within acceptable limits, despite the complexities introduced by electrification and the integration of RESs.

2. Materials and Methods

The complex power flow condition, the requirement of coordination between multiple energy resources, and the potential in improving fuel efficiency and reducing total costs necessitate the development of a grid operating tool [6]. A fundamental strategy for ensuring reliable grid operation while minimizing costs is the implementation of optimal power flow (OPF).

OPF is a mathematical optimization framework aimed at determining the optimal operating conditions for power systems. It involves minimizing an objective function, such as generation cost or power losses, while satisfying various system constraints like power balance, voltage limits, and thermal limits of the network components. The classical OPF model is well established and implemented. However, integration of RESs, energy storage systems (ESSs), and harnessing load flexibility potential necessitate the development of more dynamic and flexible OPF models that can handle the intermittent nature of RESs and take into account new parameters. A comparison of different OPF approaches for smart grids is presented in [7].

The model presented in this paper originally was described in [8]. The developed tool, an advanced OPF model implemented in Python, includes several enhanced features compared to the classical model:

- Energy storage systems (ESS)
- Wind and photovoltaic (PV) generating units with curtailment capabilities
- Load shifting
- Load curtailment
- On-load tap change transformers (OLTC)
- The problem is formulated as Multi-Period OPF

The objective function is shown in equation (1). The first term of the objective function represents the cost associated with energy generation and purchasing from the external grid. The second term accounts for the cost of shifting load. The third term is the cost associated with load curtailment.

$$\left\{\sum_{t\in T}\left(\sum_{g\in G^C} c_t^P P_{g,t}^g + \sum_{f\in L^F} c_t^F\left(P_{f,t}^{up}+P_{f,t}^{down}\right) + \sum_{l\in L^C} c^{lc} P_{l,t}^{l,curt} + \sum_{i\in N} c^V\left(e_{i,t}^{Sl,up}+e_{i,t}^{Sl,dn}+f_{i,t}^{Sl,up}+f_{i,t}^{Sl,dn}\right) + \sum_{ij\in B} c^I I_{ij,t}^{Sl^2}\right)\right\} \tag{1}$$

The following **sets** are used:

G^C : Set of conventional generators, a subset of G (set of all generators).

L^F : Set of flexible loads, a subset of L (a set of all loads).

L^C : Set of curtailable loads, a subset of L.

N : Set of buses.

B : Set of branches.

T : Set of time periods.

Constant parameters:

c_t^P : Cost of active power generation for period $t \in T$.

c_t^F : Cost of demand flexibility for period $t \in T$.

c^V, c^I : Penalties associated with voltage and current slack variables, respectively.

Decision variables:

$P_{g,t}^g$: Active power generation of generator g at time t.

$P_{f,t}^{up}, P_{f,t}^{down}$: Upward and downward flexibility provided by flexible load f at time t, respectively.

$P_{f,t}^{l,curt}$: Load curtailment of load f at time t, respectively.

$e_{i,t}^{Sl,up}, f_{i,t}^{Sl,up}$: Slack variables, real and imaginary parts of complex voltage at bus i, respectively, in upward direction.

$e_{i,t}^{Sl,dn}, f_{i,t}^{Sl,dn}$: Slack variables, real and imaginary parts of complex voltage at bus i, respectively, in downward direction.

$I_{ij,t}^{Sl^2}$: Slack variable, square of the current of the branch linking buses i and j.

In equation (1):

- The first term represents the cost of energy production from all conventional energy sources and from external grid.
- The second term is the cost of energy shifting.
- The third term is the cost of energy curtailment.
- The fourth and the fifth terms are costs associated with voltage and current slack variables respectively.

The power balance of active and reactive power in each node are given by ($\forall i \in N, \forall t \in T$):

$$P_{i,t}^{net} = \sum_{j \in N} g_{ij}(\tilde{e}_{i,t}^2 + \tilde{f}_{i,t}^2) - \sum_{j \in N} r_{ij,t}\left(g_{ij}\left(\tilde{e}_{i,t}\tilde{e}_{j,t} + \tilde{f}_{i,t}\tilde{f}_{j,t}\right)\right) + b_{ij}\left(\tilde{f}_{i,t}\tilde{e}_{j,t} - \tilde{e}_{i,t}\tilde{f}_{j,t}\right) \quad (2)$$

$$Q_{i,t}^{net} = -\sum_{j \in N} (b_{ij} + b_{ij}^{Sh})(\tilde{e}_{i,t}^2 + \tilde{f}_{i,t}^2) + \sum_{j \in N} r_{ij,t}\left(b_{ij}\left(\tilde{e}_{i,t}\tilde{e}_{j,t} + \tilde{f}_{i,t}\tilde{f}_{j,t}\right)\right) - g_{ij}\left(\tilde{f}_{i,t}\tilde{e}_{j,t} - \tilde{e}_{i,t}\tilde{f}_{j,t}\right) \quad (3)$$

where **constant parameters**:

g_{ij}, b_{ij} : Conductance and susceptance of the branch linking buses i and j, respectively.

b_{ij}^{Sh} : Shunt susceptance of the branch linking buses i and j.

Decision variables:

$P_{i,t}^{net}, Q_{i,t}^{net}$: Net active and reactive power injections at node i.

$\tilde{e}_{i,t}, \tilde{f}_{i,t}$: Real and imaginary components of voltage at bus i considering slack variables.

$r_{ij,t}$: Ratio of controllable transformer linking buses i and j.

Net active and reactive power injections could be defined by the following equations ($\forall i \in N, \forall t \in T$):

$$P_{i,t}^{net} = P_{i,t}^{g} - \left(P_{i,t}^{l} + P_{i,t}^{l,up} - P_{i,t}^{l,down} - P_{i,t}^{l,curt}\right) + \left(P_{i,t}^{Ch} - P_{i,t}^{Dch}\right) \quad (4)$$

$$Q_{i,t}^{net} = Q_{i,t}^{g} - Q_{i,t}^{l} \quad (5)$$

where **constant parameters**:

$P_{i,t}^{l}, Q_{i,t}^{l}$: Active and reactive power consumption of load located at bus i, respectively.

Decision variables:

$P_{i,t}^{Ch}, P_{i,t}^{Dch}$: Active power charging and discharging of the energy storage system located at bus i, respectively.

The real and imaginary components of voltage at bus i considering slack variables are given by ($\forall i \in N, \forall t \in T$):

$$\tilde{e}_{i,t} = e_{i,t} + e_{i,t}^{Sl,up} - e_{i,t}^{Sl,dn} \quad (6)$$

$$\tilde{f}_{i,t} = f_{i,t} + f_{i,t}^{Sl,up} - f_{i,t}^{Sl,dn} \quad (7)$$

where $e_{i,t}, f_{i,t}$ are the **decision variables** that represent real and imaginary parts of complex voltage at bus i, respectively.

The operational limits on bus voltage take the form ($\forall i \in N, \forall t \in T$):

$$e_{i,t}^2 + f_{i,t}^2 \le V_i^{max^2} + \left(e_{i,t}^{Sl,up^2} + f_{i,t}^{Sl,up^2}\right) \quad (8)$$

$$e_{i,t}^2 + f_{i,t}^2 \ge V_i^{min^2} - \left(e_{i,t}^{Sl,dn^2} + f_{i,t}^{Sl,dn^2}\right) \quad (9)$$

where V_i^{max}, V_i^{min} are **constant parameters** that represent maximum and minimum voltage magnitude at bus i, respectively.

The operational limits on longitudinal branch current take the form ($\forall ij \in B, \forall t \in T$):

$$I_{ij}^2 \leq {I_{ij}^{rated}}^2 + {I_{ij}^{Sl}}^2 \tag{10}$$

where:

I_{ij}^{rated} is **constant parameter** that represents rated current of the branch linking buses i and j.

I_{ij} is **decision variable** that represents the current of the branch linking buses i and j.

The following equality is implemented for I_{ij} ($\forall ij \in B, \forall t \in T$):

$$I_{ij}^2 = \left(g_{ij}^2 + b_{ij}^2\right)\left(\left(\tilde{e}_{i,t} - \tilde{e}_{j,t}\right)^2 + \left(\tilde{f}_{i,t} - \tilde{f}_{j,t}\right)^2\right) \tag{11}$$

The energy storage systems (ESSs) are subject to the following operational constraints ($\forall e \in E, \forall t \in T$):

$$SoC_{e,t} - SoC_{e,t-1} = P_{e,t}^{Ch}\eta_e^{Ch} - \frac{P_{e,t}^{Dch}}{\eta_e^{Dch}} \tag{12}$$

$$SoC_{e,t}^{min} \leq SoC_{e,t} \leq SoC_{e,t}^{max} \tag{13}$$

$$P_{e,t}^{Ch} P_{e,t}^{Dch} = 0 \tag{14}$$

where:

E : Set of energy storage systems.

$SoC_{e,t}$: **Decision variable** representing the state of charge of storage system e.

$\eta_e^{Ch}, \eta_e^{Dch}$: **Constant parameters** representing charging and discharging efficiencies of storage system e.

$SoC_{e,t}^{min}, SoC_{e,t}^{max}$: **Constant parameters** representing the minimum and maximum state of charge of storage system e.

Equation (12) models the ESS's energy balance, (13) maintains the SOC of the ESS unit within the admissible limits, and (14) ensures the charging/discharging exclusion. To ensure that the ESS's SoC is equal at the first and last instants of the optimization horizon, the following constraint is used ($\forall e \in E, \forall t \in T$):

$$SoC_{e,t_0} = SoC_{e,t_N} \tag{15}$$

Constraint (16) ensures that the total upward flexibility provided by flexible loads is equal to the downward flexibility ($\forall f \in L^F$):

$$\sum_{t \in T} P_{f,t}^{l,up} = \sum_{t \in T} P_{f,t}^{l,down} \tag{16}$$

The proposed model is a non-linear programming (NLP) problem. To implement the optimization problem, an open-source software package IPOPT (Interior Point OPTimizer) was utilized. The solver uses an interior-point method, and the computational complexity of the IPOPT depends on various factors, primarily the size and structure of the NLP problem. However, estimating the precise computational complexity for the presented formulation is challenging.

3. Results

The technical grid operation tool was tested in the electrical grid of Port of Sines. The grid topology is shown in figure 1.

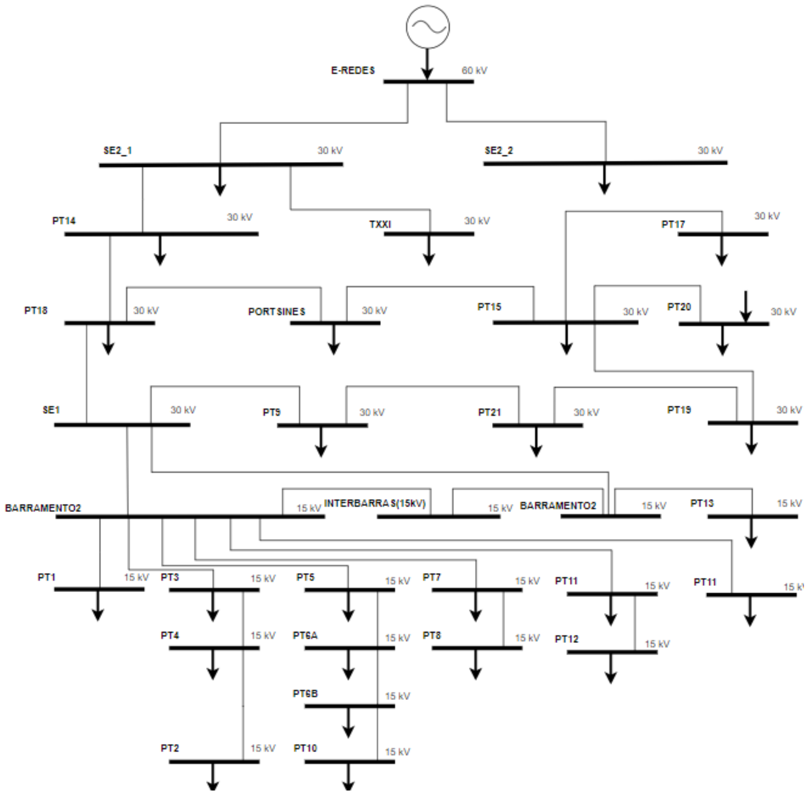

Figure 1. Electrical grid of Port of Sines

As the original grid has only one dispatchable energy source, the solution of the designed OPF shows power flow analysis of the network and could be compared with the analysis performed in conventional power flow analysis tools. The results show that the all branch power flows and the bus voltages are similar to the analysis in ETAP.

To show the performance of the developed tool, an energy storage device was assumed to be placed in node "PORTSINES". The parameters of the ESS are presented in Table 1.

Table 1. ESS parameters.

Power, MW	Capacity, MWh	Initial state of charge, MWh	Charging efficiency	Discharging efficiency
5	30	10	0.95	0.95

In the absence of a storage device, the operational cost of the system is 25970 €, with total losses amounting to 1.591 MWh. However, when a storage device is present, the operational cost decreases to 25131 €, and total losses reduce to 1.568 MWh. The cost reduction is modest due to the limited size of the ESS. Grids with a higher share of renewable energy sources (RESs) and larger ESSs can achieve more significant cost savings. However, this example demonstrates the tool's ability to reduce the operational costs of the electrical grid at the Port of Sines.

Figure 2 illustrates the power output of the ESS in relation to electricity prices. The ESS injects power into the grid when electricity prices are high and absorbs power when prices are low. This indicates that, during periods of high electricity tariffs, the optimized power flow OPF system reduces power consumption from the costly external grid, shifting consumption to times with lower tariffs.

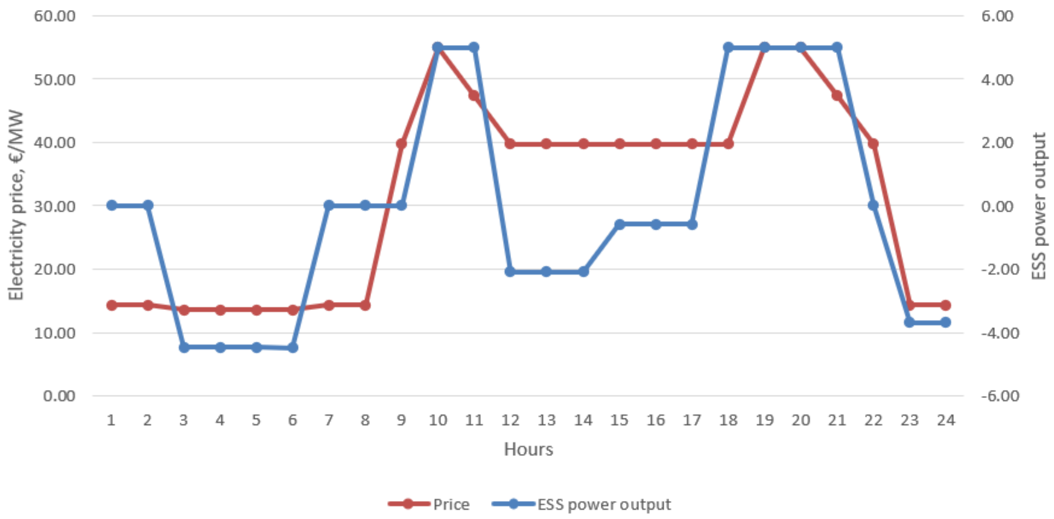

Figure 2. ESS power output.

4. Conclusions

The implementation of the Optimal Power Flow (OPF) tool for the electrical grid of a seaport marks a significant advancement in the operational efficiency and sustainability of port operations. By integrating the OPF tool, the seaport's electrical grid can optimize power distribution, minimize energy losses, and enhance the reliability of electrical supply, which is crucial for the diverse and dynamic energy demands of port activities. Given the anticipated load growth and the installation of new generating units, deploying a technical grid operating tool to the Port of Sines infrastructure will be essential.

In summary, the integration of this advanced grid operating tool can offer several benefits:

- **Cost Efficiency**: By optimizing the dispatch of local energy sources, the tool significantly reduces operational costs.
- **Reliability**: The tool ensures stable grid operation, even with a high penetration of renewable energy sources.
- **Sustainability**: Facilitates the integration of renewable energy sources, contributing to the port's sustainability goals.

Author Contributions: Conceptualization, I.P. and T.S.; methodology, I.P., M.S. and T.S.; software, I.P. and M.S.; data curation, I.P.; writing—original draft preparation, I.P. and T.S.; writing—review and editing, I.P., A.C.-G., F.C., T.S., Z.M., M.S., J.A. and E.B. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação –Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. .º 53).

Conflicts of Interest: "The authors declare no conflicts of interest."

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Automated Wave Height Estimation and Overtopping Detection from Coastal Video Data

Tochukwu Cyril Ngene[1]*, Fábio Santos[1], Tiago Abreu[2], Paulo A. Silva[3], Tiago Reis Cunha[4], Paulo Baptista[1]

1 Centre for Environmental and Marine Studies (CESAM) and Department of Geosciences, University of Aveiro, Aveiro, Portugal; ngene@ua.pt, fabioacsantos@ua.pt; renato.baganha@ua.pt
2 Centre for Environmental and Marine Studies (CESAM) and Department of Civil Engineering, Polytechnic of Porto, Porto, Portugal; taa@isep.ipp.pt
3 Centre for Environmental and Marine Studies (CESAM) and Department of Physics, University of Aveiro, Aveiro, Portugal; psilva@ua.pt
4 Department of Electronics, Telecommunications and Informatics, University of Aveiro – Instituto de Telecomunicações, Aveiro, Portugal; trcunha@ua.pt
* Correspondence: ngene@ua.pt; Tel.: +351920563022

Abstract: Coastal zones, prone to complex morphodynamic processes and extreme oceanic events, require continuous monitoring of parameters like wave height and overtopping events. Video monitoring systems have proven to be a reliable way to automatically detect, and extract features essential for effective coastal monitoring and management. This study compares and evaluates two methods for wave height estimation across various image regions and introduces a Deep Learning architecture for automatic wave overtopping detection, analyzing foam movement patterns in video data. For wave height estimation, the results show an average absolute difference of the significant wave height (Hs) of 0.1 meters between the two methods in the selected regions of interest (ROI), indicating strong agreement in the developed approaches. Regarding wave overtopping detection, the developed model demonstrates strong performance, achieving high precision (0.97) and specificity (0.97). It exhibits robust classification accuracy and generalization, as indicated by both an F1-score and an AUC-ROC (Area Under the Receiver Operating Characteristic Curve) of 0.94, highlighting its effective identification of wave overtopping events while minimizing false positives. These findings promise enhanced understanding of coastal dynamics, supporting effective infrastructure planning and disaster mitigation strategies, crucial for improving coastal management and resilience against natural disasters.

Keywords: Video-monitoring; Wave Height Estimation; Wave Overtopping Detection; Image Processing; Deep Learning

1. Background/Introduction

Coastal zones are integral to human development due to their economic and social importance. These regions experience dynamic processes over multiple temporal scales, ranging from short-term events like wave breaking and currents to long-term changes driven by climate variability. Owing to their economic value and level of urbanization, continuous monitoring is vital for understanding and forecasting the processes and impacts of human interventions, thereby ensuring coastal stability and sustainable development.

While traditional in situ measurements face challenges in cost and practicality under adverse conditions, video monitoring systems have emerged as cost-effective, reliable tools since the 1990s, offering continuous data collection and targeted observations despite operational limitations. Unmanned Aerial Vehicles (UAVs) are increasingly used in coastal monitoring due to their versatility, despite limitations in data acquisition time.

Coastal video monitoring systems have played a crucial role in morphodynamic studies, utilizing specialized image types like Timex, Variance, and Timestack. Traditional image processing methods involve techniques such as segmentation, edge detection, and texture analysis, but these can be limited by manual parameterization and environmental complexity. Recent advancements, particularly in Deep Learning (DL), have shown promise in coastal video analysis by automating the extraction of features from extensive video databases, thereby eliminating the need for manual intervention.

This study compares and evaluates two distinct methods for wave height estimation across different image regions or heights. Additionally, it introduces a novel DL architecture designed for automatic wave overtopping detection, leveraging video data to identify foam movement patterns. The integration of these methodologies is crucial for coastal management, offering validation for numerical models, enhancing wave condition monitoring, and providing essential data for predicting and preparing against coastal overtopping events. By combining these approaches, the study contributes to a comprehensive understanding of coastal dynamics and strengthens the foundation for effective coastal infrastructure planning and disaster mitigation strategies.

2. Materials and Methods

Within the scope of the NEXUS Agenda, a video camera was installed at the port of Sines. Operational since March 2024, the camera focuses on two primary goals: estimating wave heights and detecting wave overtopping at the harbor breakwater. The objective is to use the video camera installed in Sines for wave height determination and overtopping detection. However, since data from the system were not yet available (and there is insufficient data for overtopping detection), data from other locations were utilized to develop methods that will subsequently be replicated in Sines. Regarding wave height estimation, UAV video footage was captured at Costa Nova Beach on the western coast of Portugal. For overtopping detection, data from a coastal video monitoring station located at Praia dos Pescadores in Ericeira, also on the west coast of Portugal, were utilized.

2.1. Wave height estimation

For this part of the work, the video footage was obtained from Costa Nova beach at 4:15 pm on November 17, 2023, with a resolution of 3840x2160 pixels. Weather conditions during the UAV survey were favorable, with 11% cloud cover and a wind speed of 5 km/h. The wave height estimation methods employed relies on image feature segmentation, morphology, and image geometry analysis. Both methods were based on [1], which used a stadia rod to measure camera height, wave crest, trough, and still water level (SWL). Wave heights were estimated by manually extracting crest and trough points from a timestack image and scaling them with known world and image coordinates. However, this method is impractical for restricted nearshore zones and lacks automated wave crest and trough extraction. The first and second approaches use the same image processing techniques: extracting and inverting the dark areas of the image (representing wave height) to make them measurable. Wave features are measured in a symmetrical area around the optical axis. The conversion from image to world coordinates uses ground sampling distance (GSD) and camera properties like focal length and field of view. While [1] approach involves manually measuring wave crests and troughs, the second automates this process and adjusts the camera-to-image geometry for better wave height estimation.

2.2 Wave overtopping detection

Since June 2021, the Ericeira video system has been continuously capturing 10-minute videos during daylight hours, averaging 72 videos per day. The system's coverage includes the northern harbor breakwater, an area prone to overtopping. For wave overtopping detection, two primary types of deep networks were employed: Convolutional Neural Networks (CNN), specialized in extracting spatial features via convolution operations, and Long Short-Term Memory Networks (LSTM), re-nowned for their capacity to capture temporal dependencies and long-range relationships in se-quential data. The integration of CNN and LSTM within the CNN-LSTM architecture allows for concurrent processing of spatial and temporal information, rendering it extensively applicable in motion detection and classification tasks [2]. The study's methodology follows established Deep Learning procedures, including data acquisition, labeling, preprocessing, model training, hyperparameter optimization, and validation. Video footage was analyzed to extract image sequences at various times, seasons, and weather conditions. These images captured diverse foam movement patterns on a breakwater and were annotated for wave overtopping events. The dataset included 3058 labeled sequences, with 1584 showing wave overtopping and 1474 without. During the preprocessing phase, images underwent masking and cropping to isolate the specific area of interest for the study. Subsequently, they were resized to 224x224 pixels, dimensions compatible with the input requirements of the CNN employed, GoogLeNet [3]. After preprocessing, the model was trained using 85% of the videos, with the remaining 15% used for internal validation. Training involved adjusting weights over multiple epochs to improve accuracy. A CNN extracted spatial patterns from the videos, which were then analyzed by an LSTM to capture time-based relationships, enhancing detection of wave overtopping in coastal videos. Bayesian optimization refined the model's settings to maximize performance and accuracy, crucial for achieving optimal results. The final model architecture comprised a CNN (GoogLeNet) followed by a bidirectional LSTM (BiLSTM) with 1480 units evenly distributed in both directions (740 units each). This configuration integrated spatial and temporal information extracted from the videos, with the goal of accurately detecting wave overtopping events.

3. Results

3.1 Wave height estimation

For wave height estimation, the geometric correction was influenced solely by the image height, meaning that the image width had no impact on the region of interest (ROI). Consequently, a constant image width of 200 pixels was set along the optical axis. Three ROI positions were analyzed at image heights of 200-400, 400-600, and 600-800 pixels. The results demonstrate a good agreement between the two methods employed at the selected ROIs. Method 1 yields estimated Hs values of 1.37 m, 0.41 m, and 0.83 m, whereas Method 2 yields 1.47 m, 0.55 m, and 0.8 m, showing an absolute difference of 0.1 m. This demonstrates that either method can be utilized to estimate Hs in the non-breaking zone, depending on the camera and image parameters available for the application.

3.2 Wave overtopping detection

For wave overtopping detection, performance evaluation in-volved an external test set comprising 814 videos, of which 461 contained wave overtopping events and 386 did not. Similar efforts were made to ensure the representativeness and coverage of diverse conditions in the test set, mirroring those applied to the training videos. After applying the model to the test set, various performance metrics were computed to evaluate its effectiveness. The results obtained were highly satisfactory, with robust values for the calculated performance metrics: precision (0.97), recall (0.92), specificity (0.97), F1-score (0.94), AUC-ROC (0.94), and binary cross-entropy (0.21). These metrics suggest that the developed model exhibits robust capability in detecting wave overtopping events in coastal videos, demonstrating high precision and specificity. This indicates accurate identification of most wave overtopping events while minimizing false positives. Moreover, the low binary cross-entropy implies confident and well-calibrated predictions by the model. The AUC-ROC and F1-score affirm the model's effectiveness in consistently distinguishing wave overtopping events from other coastal movements, emphasizing its strong performance in classification accuracy and generalization.

4. Conclusions

Since their inception, coastal video-monitoring systems have proven to be highly effective and efficient tools for studying coastal zones, which, due to their propensity for complex morphodynamic processes, require continuous monitoring of parameters such as wave height and the quantification of events like wave overtopping. This study evaluates two wave height estimation methods and introduces a Deep Learning model for automatic wave overtopping detection using foam movement patterns in video data. The developed methods for wave height estimation are suitable for estimating Hs in the non-breaking zone, contingent upon the specifics of the camera configuration and prevailing environmental conditions. Further validation using hydrodynamic sensors is crucial to corroborate these findings across varied environmental conditions. This comprehensive validation approach aims to enhance the accuracy and reliability of wave height data, crucial for applications including coastal infrastructure design, climate change studies, and marine safety operations. The wave overtopping detection model showed promising results, supported by strong performance metrics. Configuring LSTM as a bidirectional layer (BiLSTM) notably enhanced the model's ability to capture complex temporal patterns in videos. Bayesian optimization for hyperparameter tuning significantly improved both accuracy and computational efficiency. However, challenges arose during evaluation, particularly in accurately detecting wave overtopping events later in the day due to their limited representation in the training set. Addressing this issue may require incorporating more diverse examples currently underrepresented in the dataset to further enhance model performance.

The integration of these methodologies enhances understanding of coastal dynamics and supports planning of infrastructure and disaster mitigation, emphasizing their practical relevance in coastal management and reinforcing strategies for resilience against natural disasters.

Funding: This research was supported by FCT/MCTES through national funding provided to CESAM, under grant numbers UIDP/50017/2020+UIDB/50017/2020+LA/P/0094/2020. The content was developed as part of the "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" initiative, funded by the Portuguese Recovery and Resilience Plan (PRR), project number C645112083-00000059 (investment project no. 53).

Conflicts of Interest: The authors declare no conflicts of interest.

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SUSTAINABILITY IN PORTS

Stephanie van den Berg
Portfolio manager
Strategy & Innovation and Sustainability Leader at Portbase, Rotterdam.
Keynote speaker

If we look at the subtitle of this conference, it tells us that the main goal here is to focus on the trends and challenges we are facing in the transition to digital and green maritime ports, working towards more sustainable ports.

But what does Sustainability mean? This definition can be very different for each person here today. Are you only thinking of climate change or decarbonization? Or biodiversity? Or all the SDG's of the United Nations?

For myself, I most of the time use a holistic approach towards sustainability, I would like to define Sustainability as the "social goal for people or humanity to co-exist on Earth over a long period of time."

This presentation outlines the role of Portbase in the Dutch harbours and how Portbase's sustainability strategy is contributing to making the Dutch harbour logistics more sustainabable. Portbase is the Port community system of the Netherlands, and the executive organisation of the Port of Rotterdam and the Port of Amsterdam for digitally connecting the Dutch port communities.

The mission of Portbase is to make goods and data flow through the Dutch ports and connected chains as efficiently, sustainably and safely as possible. Together with other players involved, including terminals, shipping companies, transporters and the government, Portbase is working on building the smartest port communities. The Port Community System (PCS) acts already for 20 years as the digital basis in this regard.

The sustainability strategy of Portbase is using a model that encompasses organizational, portfolio, and ecosystem impacts. Portbase is dedicated to reducing emissions, enhancing efficiency, and facilitating data-sharing for sustainability across the supply chain. Key initiatives include services and data sharing facilitating emission reduction an emission reduction dashboard, insights into upcoming sustainability regulations, and a strong focus on knowledge sharing.

Sustainability in ports involves creating ecosystems that are resilient, regenerative, and capable of supporting life in the long term. And it highlights the importance of collaboration in driving sustainability within the broader port logistics ecosystem. As stated, "Together we can turn vision into reality; through leadership and cooperation, progress becomes inevitable."

Logistics and Sustainability in the Mediterranean: A Critical Review of Challenges and Strategies for Italian Ports

Amit Kumar Singh[1,*], Yasir Hassan Khachoo[2], Oscar Rosario Belfiore[3], Giovanni Pugliano[4] and Guido D'Urso[5]

[1] Sapienza University of Rome, Rome, Italy; amitkumar.singh@uniroma1.it
[2] University of Naples Parthenope, Naples, Italy.
[3,4,5] University of Naples Federico II, Naples, Italy; oscarrosario.belfiore@unina.it; giovanni.pugliano@unina.it; durso@unina.it
* Correspondence: amitkumar.singh@uniroma1.it; Tel.: +39 3518527097

Abstract: Italian ports, integral components of the global commerce system, are under increasing pressure to adopt sustainable practices to address environmental challenges. This review explores the multifaceted aspects of logistics environmental sustainability within the context of Italian ports. Emphasizing the need for alignment between corporate strategies and sustainability, the review identifies critical dimensions such as awareness, formalization, measurement systems, governance, and budget allocation that logistics companies must integrate into their core business strategies. The environmental pressures on Italian seaport areas, often located in contaminated sites, necessitate comprehensive environmental and health protection measures due to significant risks such as mesothelioma and respiratory diseases. Additionally, the review highlights the limited adoption of quality, environmental, and social certifications in Mediterranean tourist ports, attributing this to the small size and limited entrepreneurial approach of the managing companies. Despite these challenges, the perception of Logistics Service Providers (LSPs) in Italy towards environmental issues and green strategies is generally positive, though the level of commitment varies across different company roles. The evolving global supply chain landscape underscores the critical need for mature sustainability theories and models, as evidenced by comparative studies of major ports worldwide. By examining successful strategies from international counterparts, this review aims to identify key challenges and opportunities for Italian ports. Such an exploration can provide valuable insights for optimizing operations and highlight areas requiring further investigation. Ultimately, adopting sustainable practices will enable Italian ports to enhance their competitive position globally while minimizing their environmental impact, ensuring a thriving future for both the ports and the planet. The review's findings underscore the importance of a holistic approach, integrating rigorous environmental standards and fostering a culture of sustainability within the logistics sector, thus paving the way for more resilient and eco-friendly port management practices.

Keywords: Supply chain management; Sustainability practices; Green Logistics; Port management; Environmental responsibility.

1. Introduction

1.1 Background

Italian ports play a pivotal role in the Mediterranean region, serving as vital gateways for international trade and commerce. With their strategic geographical locations, these ports facilitate the movement of goods not only within Europe but also to and from markets across the globe [1]. As integral components of the global supply chain, Italian ports are increasingly recognized for their potential to influence economic growth, regional development, and environmental sustainability [2]. However, the rapid expansion of maritime trade and the associated logistics activities have led to significant environmental challenges, necessitating a shift towards more sustainable practices.

The environmental pressures faced by Italian ports are multifaceted, encompassing issues such as air and water pollution, habitat degradation, and the management of contaminated sites [3]. Many Italian ports are situated in areas with a history of industrial activity, resulting in legacy pollution that poses serious health risks to local communities [4]. Diseases such as mesothelioma and respiratory illnesses have been linked to exposure to hazardous materials, underscoring the urgent need for comprehensive environmental and health protection measures [5]. As stakeholders increasingly recognize the importance of sustainability, the challenge lies in aligning corporate strategies with environmental stewardship to mitigate these risks [6].

1.2 Purpose of the Review

This review aims to critically explore the challenges and strategies associated with enhancing sustainability in Italian ports. By examining the current state of logistics environmental sustainability, the review seeks to identify key dimensions that logistics companies must integrate into their core business strategies. These dimensions include awareness of environmental issues, formalization of sustainability practices, development of measurement systems, effective governance, and appropriate budget allocation for sustainability initiatives.

Furthermore, the review will highlight the limited adoption of quality, environmental, and social certifications in Mediterranean tourist ports, attributing this to the small size and limited entrepreneurial approach of the managing companies. Despite these challenges, there is a generally positive perception among Logistics Service Providers (LSPs) in Italy regarding environmental issues and green strategies. However, the level of commitment to sustainability varies significantly across different roles within the logistics sector.

In light of the evolving global supply chain landscape, this review underscores the critical need for mature sustainability theories and models. By drawing on comparative studies of successful strategies implemented in major ports worldwide, the review aims to identify key challenges and opportunities for Italian ports. Ultimately, the findings will provide valuable insights for optimizing operations and highlight areas requiring further investigation. By adopting sustainable practices, Italian ports can enhance their competitive position on the global stage while minimizing their environmental impact, ensuring a thriving future for both the ports and the planet.

2. Related Work

Sustainability in logistics has emerged as a critical area of focus in recent years, driven by the need to balance economic growth with environmental stewardship and social responsibility. The concept encompasses a wide range of practices aimed at minimizing the environmental impact of logistics operations while maximizing efficiency and profitability. Logistics activities contribute significantly to global greenhouse gas emissions, highlighting the urgent need for companies to adopt sustainable practices [7]. These practices include optimizing transportation routes, utilizing alternative fuels, reducing waste, and implementing green technologies. The increasing regulatory pressures and consumer demand for environmentally friendly practices further underscore the importance of sustainability in logistics. As stakeholders become more aware of the environmental implications of logistics operations, the integration of sustainability into corporate strategies has become not just a competitive advantage but a necessity.

In the context of Italian ports, the environmental challenges are particularly pronounced. Many of these ports are situated in urban areas with high population densities, leading to conflicts between port operations and local communities [8]. The environmental pressures faced by Italian ports include air pollution from shipping activities, water contamination from runoff, and noise pollution affecting nearby residents [9]. A significant concern is the presence of contaminated sites, often a legacy of past industrial activities. Many Italian ports are in areas with high levels of soil and water contamination, posing risks to both human health and marine ecosystems [10]. The remediation of these sites is not only a regulatory requirement but also a moral obligation to protect local communities from health hazards associated with exposure to toxic substances [11]. The regulatory framework governing environmental practices in Italian ports is complex and multifaceted, with the European Union establishing stringent regulations aimed at reducing emissions and promoting sustainable practices in the maritime sector [12]. However, the implementation of these regulations can be inconsistent, often hampered by bureaucratic challenges and a lack of resources at the local level [13].

Despite the growing awareness of sustainability issues, the adoption of sustainable practices in Italian ports remains limited. Many logistics companies operating in Italian ports have yet to fully embrace sustainability, often due to a lack of resources, knowledge, and commitment [14]. The small size of many managing companies complicates the situation, as they may lack the capacity to invest in sustainable technologies and practices. While there is a general awareness of environmental issues among Logistics Service Providers (LSPs) in Italy, the level of commitment to sustainability varies significantly across different roles within the logistics sector [15]. Research by Russo and Tappia (2022) indicates that while top management may recognize the importance of sustainability, operational staff often lack the training and resources needed to implement sustainable practices effectively [16]. This disconnects between awareness and action highlights the need for targeted training and support to foster a culture of sustainability within logistics companies [17].

Another significant barrier to sustainability in Italian ports is the limited adoption of quality, environmental, and social certifications [18]. Many managing companies are small and may not prioritize certification due to perceived costs and complexity [19]. This lack of certification can hinder the ability of ports to demonstrate their commitment to sustainability and attract environmentally conscious customers [20]. The limited uptake of certifications also reflects a broader trend in the Mediterranean region, where smaller ports often struggle to implement comprehensive sustainability frameworks due to resource constraints and a lack of strategic vision [21].

To address these challenges, Italian ports can learn from successful sustainability strategies implemented in other countries. Comparative studies reveal that ports that have adopted comprehensive sustainability frameworks tend to outperform their peers in terms of environmental performance and operational efficiency. For instance, the Port of Hamburg has implemented a range of initiatives aimed at reducing emissions and promoting sustainable practices, including the use of shore power for vessels and investments in green logistics infrastructure [22]. Similarly, the Port of Los Angeles has developed a Clean Air Action Plan that has successfully reduced air pollution from port operations by over 50% since its implementation [23]. These examples highlight the potential for Italian ports to enhance their sustainability efforts by adopting best practices from their international counterparts.

The key lessons from these successful ports include the importance of stakeholder engagement, the need for robust measurement systems to track progress, and the value of integrating sustainability into corporate strategies. By fostering collaboration among stakeholders, including government agencies, port authorities, and logistics companies, Italian ports can create a more conducive environment for sustainable practices. Furthermore, the establishment of clear sustainability goals and performance metrics can help guide the implementation of initiatives and ensure accountability. As the global supply chain landscape continues to evolve, the integration of sustainability into logistics operations will be essential for enhancing the competitive position of Italian ports while minimizing their environmental impact.

3. Methodology

This review employs a systematic approach to analyze the challenges and strategies related to sustainability in Italian ports. The methodology consists of several key steps: first, a comprehensive literature search was conducted to gather relevant academic articles, industry reports, and policy documents related to logistics sustainability, environmental challenges, and port management. Databases such as Google Scholar, JSTOR, and Scopus were utilized to identify peer-reviewed articles published in the last decade, ensuring that the review reflects the most current trends and practices. The search terms included "sustainability in logistics," "Italian ports," "environmental challenges," and "sustainable port management."

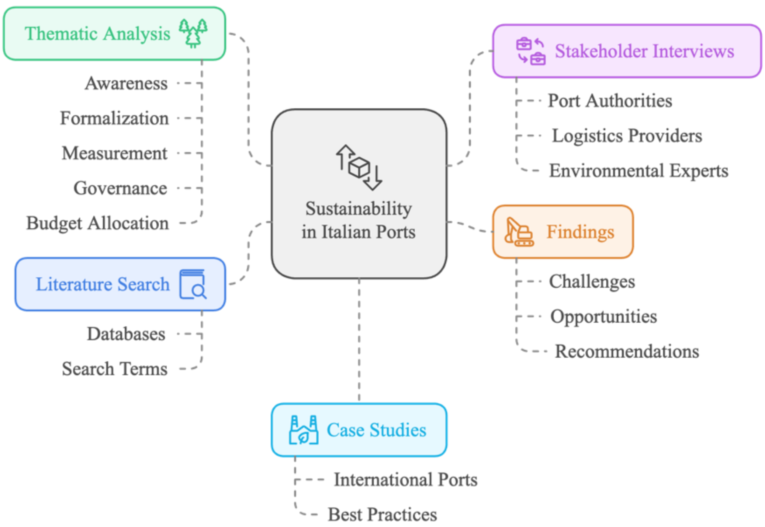

Figure 1. Framework for Analyzing Sustainability in Italian Ports

This flow diagram illustrates the components and methodology used in analyzing sustainability in Italian ports. It includes thematic analysis of critical dimensions (awareness, formalization, measurement, governance, and budget allocation), stakeholder interviews with port authorities, logistics providers, and environmental experts, a literature search through databases, and case studies of best practices from international ports. The findings cover challenges, opportunities, and recommendations for enhancing sustainability in Italian ports. Following the literature search, the collected data were categorized into thematic areas, including awareness of sustainability issues, formalization of sustainability practices, measurement systems, governance structures, and budget allocation for sustainability initiatives. This thematic analysis allowed for a structured examination of the various dimensions of sustainability within the context of Italian ports. Additionally, case studies of successful sustainability initiatives from international ports were identified and analyzed to draw comparisons and extract best practices that could be applicable to the Italian context.

To supplement the literature review, qualitative interviews were conducted with key stakeholders in the logistics and port management sectors, including port authorities, logistics service providers, and environmental experts. These interviews aimed to gather insights on the current state of sustainability practices in Italian ports, the perceived barriers to implementation, and the level of commitment among stakeholders. The qualitative data were analyzed using thematic coding to identify common themes and patterns that emerged from the interviews.

Finally, the findings from the literature review and stakeholder interviews were synthesized to develop a comprehensive understanding of the challenges and opportunities for enhancing sustainability in Italian ports. This synthesis not only highlights the critical dimensions of sustainability that need to be addressed but also provides actionable recommendations for stakeholders to improve their sustainability practices.

4. Results and Discussion

The analysis reveals a significant gap between sustainability awareness and action in Italian ports. While many Logistics Service Providers (LSPs) recognize the importance of sustainable practices, only 40% have formal policies in place, largely due to limited resources and expertise, especially among SMEs. Five critical dimensions—awareness, formalization, measurement systems, governance, and budget allocation—are essential for sustainability adoption. However, formalization and measurement systems remain major obstacles, with only 25% of companies tracking their sustainability performance. Positive examples from international ports, such as Rotterdam and Los Angeles, inspire stakeholders in Italy, though regulatory challenges, limited funding, and insufficient collaboration hinder progress.

To bridge the gap between awareness and implementation, Italian ports could benefit from tailored frameworks that help SMEs formalize sustainability practices and establish measurement systems with key performance indicators. Policymakers could support this transition by providing incentives like grants or tax breaks for sustainable initiatives, while fostering collaboration among port authorities, logistics companies, and communities to drive more inclusive strategies. Enhanced stakeholder engagement, including workshops and forums, can further facilitate knowledge sharing, creating a stronger culture of sustainability across the logistics sector.

Ultimately, these findings highlight the potential for Italian ports to adopt successful international practices, address key barriers, and establish themselves as leaders in Mediterranean sustainability. By prioritizing action and collaboration, Italian ports can strengthen their competitive position, reduce environmental impact, and contribute to a more sustainable future for the region.

5. Conclusions

This review has critically examined the challenges and strategies associated with enhancing sustainability in Italian ports, highlighting the urgent need for a paradigm shift in how logistics operations are managed within this vital sector. The findings indicate that while there is a growing awareness of sustainability issues among stakeholders, a significant gap remains between this awareness and the actual implementation of sustainable practices. The limited formalization of sustainability policies, inadequate measurement systems, and insufficient budget allocation for sustainability initiatives are key barriers that must be addressed to foster meaningful change.

The analysis identified five critical dimensions influencing the adoption of sustainability in Italian ports: awareness, formalization, measurement systems, governance, and budget allocation. Among these, formalization emerged as a particularly pressing concern, especially for small and medium-sized enterprises (SMEs) that often lack the resources and expertise to develop comprehensive sustainability strategies. The review also underscored the importance of stakeholder engagement, revealing that collaboration among port authorities, logistics service providers, and local communities is essential for creating a culture of sustainability.

Moreover, the review highlighted successful sustainability initiatives from international ports, such as those in Rotterdam and Los Angeles, which serve as valuable benchmarks for Italian ports. By learning from these best practices and adapting them to the local context, Italian ports can enhance their sustainability efforts and improve their competitive position in the global logistics landscape.

In conclusion, the path toward sustainability in Italian ports requires a concerted effort from all stakeholders involved. Policymakers must create an enabling environment that encourages investment in sustainable practices, while logistics companies need to prioritize the integration of sustainability into their core business strategies. By addressing the identified challenges and leveraging the opportunities presented by successful international examples, Italian ports can not only minimize their environmental impact but also contribute to a more sustainable future for the Mediterranean region. Ultimately, the adoption of sustainable practices will ensure the long-term viability of Italian ports, benefiting both the economy and the environment.

Author Contributions: Singh and Khachoo developed the research concept. Singh designed the methodology. Belfiore managed the software. Singh, Khachoo, and Pugliano validated the data. Khachoo conducted the formal analysis. Pugliano handled the investigation. D'Urso provided resources. Singh curated the data. Singh wrote the first draft. Khachoo and Belfiore reviewed and edited the manuscript. Pugliano created the visualizations. D'Urso supervised the project. Singh administered the project. Khachoo secured funding. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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Characterization of the energy consumption and GHG production on the Port of Sines, Portugal

Teresa Batista[1]*, Carmen Vásquez[1], Rodrigo Ramírez-Pisco[2], Luís Manuel Navas[3], João Figueira de Sousa[4], Patrícia Silva[5], Fátima Baptista[6], Lucas Marinho[1], Adriana Correa[3], João P. Araújo[7], Eduardo Bandeira[7]

[1] MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, Institute for Advanced and Research, University of de Évora, Évora, Portugal. mtfb@uevora.pt, carmen.vasquez@uevora.pt, lucas.marinho@uevora.pt.
[2] RITMUS – Universitat Carlemany, Andorra, Andorra
[3] RITMUS – Universidad de Valladolid, Valladolid, España
[4] Nova University of Lisbon, Lisbon, Portugal. sjaf@fcsh.unl.pt,
[5] Figueira de Sousa, Transportes e Mobilidade, Lisboa, Portugal. patricia.silva@figueiradesousa.pt
[6] MED – CHANGE, Pólo da Mitra, University of Évora - Évora, Portugal. fb@uevora.pt.
[7] APS – Sines, Portugal. joao.araujo@apsinesalgarve.pt, eduardo.bandeira@apsinesalgarve.pt
* Correspondence: mtfb@uevora.pt Tel.: +351 963 257 296

Abstract: This document includes the characterisation of the energy consumption and carbon footprint of the Port of Sines, Portugal, for the period 2018-2022, as the basis for establishing policies for a sustainable energetic transition for the port. The proposed calculation model is detailed using different information sources and classifies the emissions in three scopes. For each terminal, monthly and annual energy consumption and carbon footprint are calculated, considering land activities (land vehicles – trains, trucks, terminal equipment, and personnel pendular displacements) and maritime activities (ship, tugboats, and pilot boats movements) as well as asymmetric data, due to the different port activities. The results show that more than 99% of the Port's total energy consumption and emissions are due to the operations and activities of the several terminals. On average, the Port of Sines consumes 422,378.45 MWh/year and has left a carbon footprint of 236,254.01 tCO_2eq/year.

Keywords: Carbon footprint estimation, calculation models for maritime ports, energy consumption, energy characterization.

1. Introduction

The adoption of low-energy and low-emission systems in maritime ports benefits logistics in the global transport chain, which is urged to reduce its contribution to global warming [1-3] and comply with regulatory frameworks [4-8]. Developing a decarbonisation plan for port activity, based on the quantification of emissions, is identified as an important task for managers [1], users [10, 11] and researchers in this area [1, 12].

The calculation of the carbon footprint represents a methodological complexity and a greater requirement of information as its rigorousness increases. The fact of involving external agents to the organisation itself considerably increases its complexity, due to the amount of information required and the difficulty of making it available [13]. However, the greater detail and the comprehensive way it is carried out makes it a suitable tool for the establishment of emission reduction policies and thus for achieving carbon neutrality [14].

The Port of Sines has a location and strategic importance that distinguishes it in the maritime industry of Portugal [15]. This paper shows the energy characterisation and carbon footprint of the Port of Sines, in Portugal, for the period of 2018-2022. This characterisation includes the calculation model and considers several sources of information, including that of its concessionaires. The following paper contains the general description of the methodology, methods and materials used. The general results obtained per terminal, considering the diversity of load types and emission factors and, finally, the most relevant conclusions of the study.

2. Material and methods

The monthly and annual calculation of the energy consumption and carbon footprint of the land and maritime transport in the jurisdiction area of the Port of Sines for the period 2018-2022 is carried out based on a detailed calculation model that considers the diversity of terminals it currently has. This area is distributed in 6.31 and 147.5 km² land and sea, respectively. To achieve the goal of carbon neutrality, the International Maritime Organization (IMO) establishes 2008 as the base year for comparison, with targets defined for the years 2050 and 2100 [4]. However, another base year may be selected depending on data availability [16]. Tank to wheel (TTW) emissions are considered [17], classified according to the tree scopes of the Greenhouse Gas (GHG) Protocol methodology [18], recommended by the International Association of Ports and Harbors (IAPH) for similar studies [19]. For each scope, emissions from land-based and maritime activities, as well as stationary and mobile activities, have been estimated for the Port Jurisdiction Area (AJPS, acronyms in Portuguese), along with each type of terminal and the different types of services.

Scope 1 [18] considers the consumption of fossil fuels used by the Port Authority (APS, acronyms in Portuguese) for land and maritime activities carried out within the jurisdiction area. For Scope 2 [18], the consumption is obtained based on the purchase and sale of electricity by APS. Scope 3 [18] includes the calculation of energy consumption for the maritime and land transport activities of each terminal and the services provided. The calculation of Scope 3, although it encompasses indirect emissions, is crucial for establishing effective emission reduction policies at the port, as it allows for the identification of the main emission sources associated with the concessionaires and the implementation of joint measures.

The Port of Sines has five (5) main terminals with private concessions specialising in containerised cargo (TCS, acronyms in Portuguese), liquid bulks (TGL, acronyms in Portuguese), natural gas (TGN, acronyms in Portuguese), petrochemical (TPQ, acronyms in Portuguese) and general cargo (TMS, acronyms in Portuguese). They have different maritime and inland infrastructures, technologies, disruption risks, and inland transport modes for their goods, among others. In addition, it provides services to fishing and marina ports, tugboats and to the industrial zone. This diversity means that the calculation of energy consumption and carbon footprint is differentiated for each type and with asymmetric data [20]. The carbon footprint of the Port of Sines shows a high variability in data due to the diversity of its operations, resulting in an asymmetric distribution of the data. This heterogeneity complicates the application of standard statistical models and requires a more detailed analysis for each terminal.

Table 1 and Figure 1 show a description of the terminals, and, in general terms, the aspects considered in each domain in the methodology, respectively.

Table 1. Port of Sines Terminals

Terminal	Depth (m)	Cargo type
TCS	17	Container
TGL	28	Crude oil, refined oil, liquefied petroleum gas, methanol, and chemical naphtha.
TGN	15	Liquefied natural gas
TPQ	12	Propylene, ethylene, butadiene, ethyl tertiary butyl ether, ethanol, methyl tertiary butyl ether, aromatic mixtures, and methanol.
TMS	18	Dry bulk, general cargo and ro_ro

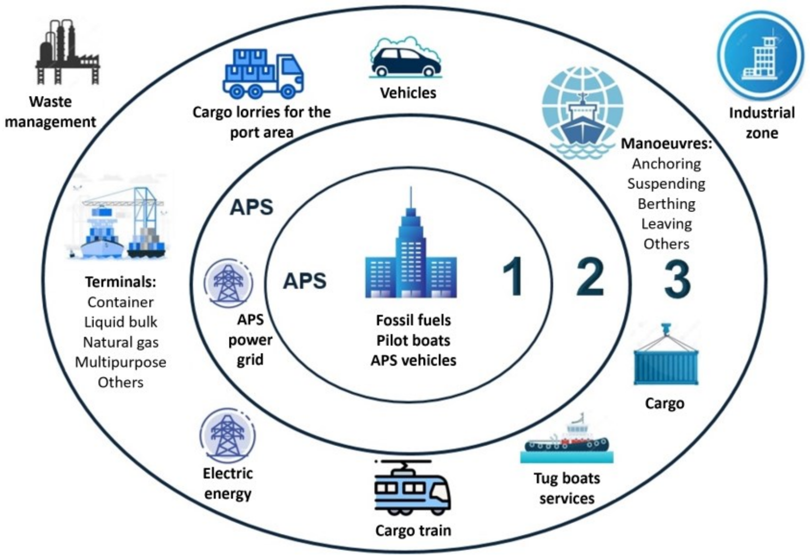

Figure 1. GHG Protocol Scopes (1,2 and 3) [18]: applications to the AJPS

The calculation methodology considers the consumption of the fuels used and their respective emission factors. In addition, the statistics of ships and cargo managed by terminal for the period 2018-2022 carried by APS.
For Scope 1 [18], the following fuels are considered [3, 16]:

- Natural gas for the boilers.
- Diesel fuel for the emergency power plant.
- Diesel fuel for employees' collective transport vehicles.
- Diesel fuel and gasoline for private employee transport vehicles.
- Diesel fuel for the pilot boats who steer the ships within the AJPS.

Scope 2 [18] includes electricity consumption based on records kept by APS and emission factors from the Portuguese Environment Agency (APA, acronyms in Portuguese) [21].

Scope 3 [5, 16, 18, 21, 22] includes the calculation of energy and emissions from the activity carried out by the concessionaires in the different terminals. Energy consumption and carbon footprint are calculated for the end use of electricity and for maritime and land transport.

For maritime transport, information from the Port Single Window (JUP, acronyms in Portuguese) and logistics (JUL, acronyms in Portuguese) on ship manoeuvres and factors published by the European Environment Agency (EEA, acronyms in Spanish) are used [4]. This information includes nearly 70,000 manoeuvres, covering:

- Type of ship, IMO id and power of main engines, among others.
- Type and times of manoeuvres per terminal [24]. Passenger Locator Form (PLF)-Entrance, anchoring, suspending, berthing, docking, departing and PLF-Departure manoeuvres were considered.

The review of different studies shows that, in recent years, many ports have started to calculate their carbon footprint and report it. This is a positive sign in terms of the "greening" of ports. However, there is scope for further enhancement for land transport, the following fuels are considered [3, 16]:

- Diesel and gasoline for the pendular movement of employees by terminal in private and collective vehicles.
- Diesel for the transport of cargos by container, general cargo and cryogenic trucks for natural gas.
- Electric power for the train line for container transport.

3. Results

The calculations of energy consumption and carbon footprint were made on a monthly and annual basis, considering the load managed by each terminal, based on the statistics kept by APS. Tables 2 and 3 show the average annual value for Scope 3 (which corresponds to more than 99% of the totals) and for each Scope, respectively. Until 2021, the TMS was managed by a dry bulk concessionaire. From 2022 ahead, the concessionaire of this terminal changes its purpose to handling general cargo, thus, only calculations relating to the year 2022 are included in the table.

Table 2. Energy characterisation and carbon footprint of Scope 3 of the Port of Sines. Average value for the period 2018-2022

Font	TCS	TGL	TGN	TPQ	TMS	Others	Scope 3	Scope 3 (%)
Energy consumption (MWh)								
Electric energy	17,163.28	4,776.63	62,053.12	31,634.13	2,209.22	733	118,569.38	25.21
Land Transport	3,032.28	214.00	228.95	86.60	455.07	--	4,016.90	0.85
Maritime Transport	59,356.17	192,397.26	19,142.65	4,425.97	21,126.60	51,366	347,814.65	73.94
Total	79,551.73	197,387.88	81,424.72	36,146.70	14,860.23	52,099	461,470.26	100.00
Carbon footprint (tCO_2eq)								
Electric energy	3,405.46	968.07	12,269.49	6,218.96	523.05	150	23,535.03	23.88
Land Transport	408.09	28.76	30.81	11.66	61.24	--	540.60	0.55
Maritime Transport	41,494.34	135,238.27	5,087.54	3,109.00	14,886.23	9,947	74,524.11	75.61
Total	45,307.89	136,235.14	17,359.48	9,339.62	15,444.52	10,097	98,599.74	100.00

Table 3. Energy characterisation and carbon footprint of the Port of Sines. Average annual value for the period 2018-2022

Energy consumption (MWh)							
Scope	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**	**Average (%)**
1	1,758.78	2,024.81	1,802.64	1,799.73	1,601.66	1,797.52	0.43
2	1,600.12	1,613.60	1,367.00	1,643.00	1,504.00	1,545.54	0.37
3	386,686.69	380,522.45	413,976.29	536,283.83	377,707.63	698,392.30	99.21
Total	390,045.59	384,160.87	417,145.93	539,726.56	380,813.29	422,378.45	100.00
Carbon footprint (tCO_2eq)							
Scope	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**	**Average (%)**
1	593.94	742.29	593.73	579.18	545.99	611.03	0.27
2	459.00	376.00	251.00	266.00	205.00	311.40	0.14
3	226,347.11	179,767.30	217,452.23	300,064.52	194,915.94	223,709.42	99.59
Total	227,400.05	180,885.60	218,296.96	300,909.70	195,666.93	224,631.85	100.00

4. Conclusion

The following work includes the energy characterisation and calculation of the carbon footprint of the Port of Sines currently managed by APS for the period 2018-2022. This characterisation is carried out for each of its terminals and service provision in the entire jurisdiction area of the Port of Sines. The diversity of activities in the terminals means that this calculation is carried out specifically for each type and with asymmetric data. Within this framework, it is shown that Scope 3, due to the activity of the concessionaires and the movement of goods, contributes with more than 99% of the energy consumption and carbon footprint of the Port as a whole. On average, the Port of Sines consumes an average value of 422,378.45 MWh/year and has a carbon footprint of 224,631.85 tCO_2eq/year.

Acknowledgments: Content produced within the scope of the *Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade"*, financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. º 53)

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Applications of Sentinel-5P Satellite Data for Monitoring Maritime Pollution

Saad Ahmed Jamal [1], Crismeire Isbaex [1] and Teresa Batista [1,*]

1 MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, University of Évora, Apartado 94, 7002-544 Évora, Portugal.
E-mail: saad.jamal@uevora.pt; cisbaex@uevora.pt; mftb@uevora.pt.
* Correspondence: mftb@uevora.pt;

Abstract: Atmospheric monitoring through space-based observations has been ongoing for more than three decades. Satellite data is being used by maritime policy makers. This paper reviews the uses of Sentinel-5 Precursor satellite for port air quality management. A thorough analysis of Web of Science was carried out to extract relevant literature and scrutinise research articles. PRISMA framework was employed for the systematic literature review. Through literature, multiple use cases of Sentinel-5P were discovered which also presented new research avenues to be explored. Setinel-5 data can be utilised for spatial and temporal analysis of pollutant concentration levels in the Ports of Portugal. Though aerial surveys, such as by using Unmanned Aerial Vehicles (UAV), provide estimations of Greenhouse Gases (GHGs) at a higher resolution, they can only be used for specific purposes as using this technology is expensive and it is not feasible for daily monitoring. Sentinel-5 based measurement, on the other hand, provides continuous monitoring for the air quality which aids the ground surveys in order to capture and penalise the big sources of emissions and therefore, support in environmental management according to the sustainable development modern policies and regulations.

Keywords: tropomi; emission; ports; maritime; prisma; remote-sensing.

1. Introduction

The maritime transport industry faces significant challenges in reducing greenhouse gas (GHG) emissions, accounting for 3% of global emissions, with a 20% increase in the last decade [1]. With over 80% of world trade carried by ships, and a global fleet with almost 99% reliant on conventional fuels, decarbonising the sector and monitoring these emissions become essential to mitigate the environmental impact of maritime transport [1].

The Sentinel-5 Precursor mission, launched on 13 October 2017 by European Space Agency (ESA), has significantly advanced our ability to monitor atmospheric composition, identify sources of pollution and in monitoring GHGs [2]. It is part of the European earth monitoring programme called Copernicus previously known as Global Monitoring for Environment and Security (GMES) [3]. This mission is particularly valuable in the maritime context, where emissions from shipping contribute significantly to air pollution, ozone and climate change. It monitors key trace gases and aerosols that affect air quality on a global scale and supports the Copernicus Atmosphere Monitoring Service (CAMS) by providing high spatial resolution data and offering a daily global revisit time [3].

Sentinel-5 carries a state-of-the-art spectrometer Tropospheric Monitoring Instrument (TROPOMI). It is an advanced nadir-viewing Differential Optical Absorption Spectrometer (DOAS) with passive grating imaging and push broom configuration that has a swath width of 2600 km and a pixel size of 5.5/3.5 km^2 [4]. It is equipped with 7 spectral bands for which three levels of data products were processed by ESA. Sentinel-5 Level-0 Product is not distributed to end users. There are 6 products for Level-1B and 11 products for Level-2 which are available online for the public [5]. The levels are defined according to levels of processing applied on the original data. Sentinel-5 measures various atmospheric gases across multiple wavelengths. These wavelengths are crucial for understanding specific pollutants like Nitrogen Dioxide (NO_2), Methane (CH_4), Ozone (O_3), Formaldehyde (HCHO) tropospheric vertical columns (mol/m^2), Ultra Violent Aerosol Index (AER_AI) and geophysical parameters of clouds [5]. Saliba et al. [2], in their analysis of the movement of 85,000 vessels around Malta over a 10-year period deduced that in 2015, as shown in figure 1, the highest ship emission is Carbon Dioxide (CO_2) which is about 95.75% of total share of emissions. NO_2 is the second while SO_2 is the third highest with 2.34% and 1.40% share respectively.

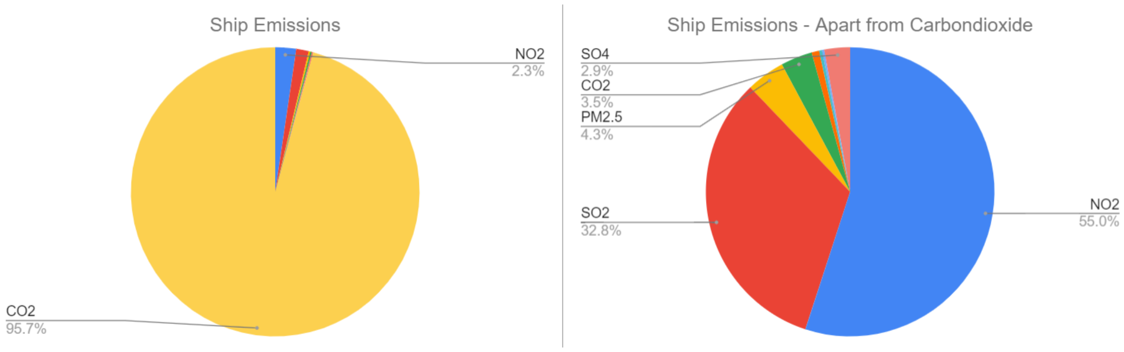

Figure 1: Shows the percentage of emissions from ships in 2015, data extracted from [2].

In this context, this study aims to conduct a systematic review analysis focusing on the application of Sentinel-5 data in the global maritime sector. A comprehensive understanding of the applications of Sentinel-5 data in the maritime sector necessitates a thorough systematic review [6] and bibliometric analysis of the existing literature. This will allow to identify important research gaps and guide future research efforts.

2. Materials and Methods

In this work, theoretical background on the use of Sentinel-5 data in the maritime context is provided. The aspects covered create the basis for understanding the chosen methodology and the results obtained. The bibliometric analysis was conducted based on the following steps:

1. **Identification stage**: in this phase, keywords were defined to fully capture the topic of the study. The search process was carried out in two stages in the Web of Science (WoS) database. The search was conducted with specific and comprehensive keywords, using the following search string: ('sentinel-5' OR 'tropomi') AND ('emission' OR 'pollution*') AND ('ship*' OR 'vessel*' OR 'maritime*' OR 'ais' OR 'port*' OR 'monitor*' OR 'fuel*' OR 'optimizat*' OR 'anthropogenic' OR 'concentrat*' OR 'machine learning' OR 'artificial*').
2. **Database analysis stage**: In Web of Science (WOS), the selection of publications was restricted to articles, proceedings papers, and review articles published in English.
3. **Analysis stage**:
   3.1 **Co-occurrence network**: VOSviewer software was used to visualise and analyse the co-occurrence network of keywords using binary counting, allowing the identification of central themes and their interrelationships in the selected literature. In the analysis conducted with VOSviewer, a standard minimum threshold of 10 occurrences was applied for each term. Out of the 17,055 terms initially identified, 269 met this minimum frequency criterion and were selected for further analysis. To

further refine the selection, the software calculated the relevance of each of these 269 terms. By using VOSviewer's default configuration, 60% of the most relevant terms were selected, resulting in a final set of 161 terms for detailed analysis. This filtering process allowed focusing on the most significant and frequent terms, facilitating the identification of patterns and central themes in the analysed literature.

3.2 Screening and eligibility stage: The screening and eligibility process for publications followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework [6]. This method ensured a systematic and transparent approach in selecting relevant studies for the review.

3. Results

In the VOSviewer analysis, 161 terms were grouped into three main clusters, with 54 terms in the red cluster (analysis of models using Sentinel-5), 51 in the green cluster (assessment of pollution and impacts on air quality), and 49 items in the blue cluster (estimates of greenhouse gas emissions). Figure 2 shows the result through visualisation of co-occurrence by overlay for the keywords that were found in the publications.

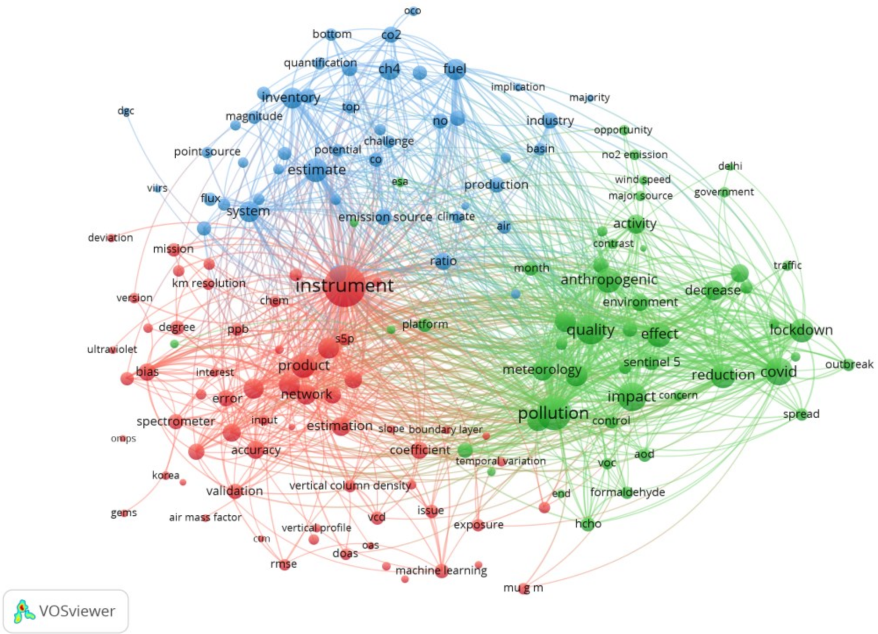

Figure 2: Co-occurence map of keywords.

A total number of 655 identified literature was found for Sentinel-5. By applying PRISMA methodology, 58 papers were finally selected for detailed review. In the literature, Sentinel data, along with in-field or ground truth data integrated into models, is being transformed into services for tracking climate patterns, environmental conditions, and security-related concerns. The primary services are mainly focused on Earth system domains like Atmospheric, Marine, and Land, as well as other domains like Climate Change, Security, and Emergency Management [3].

The established principles of the Sentinel data policy allow for free and open access to all users. Essentially, anyone can access the acquired Sentinel data, with no distinction made between public, commercial, or scientific use, nor between European and non-European users, though registration is required. Additionally, the licenses for the Sentinel data are provided free of charge.

To monitor spatial and temporal patterns of NO_2 pollution, a comparison of the effectiveness of TROPOMI NO_2 data was made with surface-level concentration measurements in the capital of Spain for the year 2022 [7]. The analysis revealed a high linear correlation coefficient ($r = 0.78$) when comparing daily Level-3 tropospheric TROPOMI NO_2 data with ground-based measurements from air quality monitoring stations during satellite overpass times [7]. This suggested that TROPOMI data can be further utilised to develop pollution mitigation policies. Another study has addressed systematic underestimation in the Sentinel-5P NO_2 data by incorporating NO_2 vertical profile information derived from Multi-axis Differential Optical Absorption Spectroscopy (MAX-DOAS) measurements in Brussels [8]. The underestimation was attributed to the use of inappropriate inferred NO_2 profile shape data in the satellite retrieval process. However, a total of one year of data from Sentinel-5P TROPOMI was validated. Analysis over bigger data can result in more confidence with the results.

Rodriguez Valido et al. [9] evaluated NO_x emissions and their impacts on air quality in the inland waters of the Canary Islands, Spain, focusing on maritime transport activity contributions. A strong spatial correlation was observed between NO_x levels and regular shipping routes connecting the major islands, especially in weekly averaged data. Notable increases, up to 2.0×10^{15} molecules/cm^2, were detected along the central areas of these primary shipping lanes. The multitemporal NO_2 data from TROPOMI allowed to estimate the contribution of ship traffic to NO_x emissions in this intricate environment, which is also affected by land-based emissions. The effects of the pandemic lockdown on NO_2 concentrations produced a reduction of approximately 40% in land areas on a monthly scale. This reduction was moderate in the maritime zone during the same period. The levels of NO_2 found in the port area, with mean values of 1.22×10^{15} molecules/cm^2 and maxima of 2.97×10^{15} molecules/cm^2, were comparable to those found over land and higher magnitude than the oceanic, non-anthropogenic background values of 7.1×10^{14} molecules/cm^2. The authors confirmed that the sensor's cumulative signal over various time periods exhibits a spatial pattern similar to the distribution of vessels in the Tenerife–Gran Canaria channel.

While investigating greenhouse gas emissions, Saliba et al. [2] found that fuel type and engine size have a significant impact on ship emissions. Ships using diesel engines powered by heavy fuel oil, emit gases such as SO_2. Strict regulations mandating the use of fuel oil with a maximum sulfur content of 0.1% have significantly reduced sulfur emissions in affected areas. The study used Ship Traffic Emission Assessment Model (STEAM), Automatic Identification System (AIS) dataset, and Sentinel-5 data to assess emissions at the Giordan Lighthouse in the Malta Channel. The results indicated that EU sulfur regulations led to a reduction in emissions. However, the impact in the Mediterranean Sea was limited, as passenger vessels account for only 12% of total fuel consumption, leading to an approximate 5% decrease in SO_x emissions. Sentinel-5 measurements confirmed the effectiveness of these new regulations, with analysis also including COVID-19 impacts on emission patterns. With the employment of machine learning models, NO_2 plumes are being detected with good performance along with the shipping patterns [10]. This is useful for emission compliance studies and inventory. A cloud computing platform such as Google Earth Engine (GEE) can be used for spatial and temporal analysis of concentration levels of pollutants at the Ports of Portugal [11].

4. Conclusions

In the maritime sector, the TROPOMI instrument on the Sentinel-5 satellite has been employed to monitor air quality, pollution and GHGs. Its accuracy has been validated and it is now being used as a conventional method worldwide for monitoring of atmospheric pollution levels. The analysis of NO_x distribution over time as derived from satellite data revealed consistent patterns aligned with the primary sources of emissions in specific geographic areas. The free and open availability of Sentinel-5 data, coupled with its ability to accurately identify atmospheric gases, makes it a valuable tool for detecting emission hotspots and detection of ship plumes. Due to its higher spatial resolution than previously existing satellite data such as MODIS (Terra/Aqua) and Aura Ozone Monitoring Instrument (OMI), such applications became possible. Collecting daily data on pollutants provides important insights for environmental management and maintaining health regulations. A temporal assessment of air quality for ports using satellite data would provide a good understanding of the current situation according to the established standards. Future projections through the use of analytical methods such as regression and machine learning models can be made to predict future concentration levels in the ports.

Acknowledgments: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53). The authors would also like to acknowledge the support by NEXUS team members including Francisco Borges, Lucas Marinho, Luis Rosa, Carmen Vasquez and Venina Peixeiro.

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Carbon sinking through coastal landscapes: Identifying opportunities for the port of Sines, Portugal

Lucas Marinho [1], Conceição Freire[2] and Teresa Batista[3] *

[1] MED – Mediterranean Institute for Agriculture, Environment and Development, Universidade de Évora, Évora, Portugal. lucas.marinho@uevora.pt
[2] Chaia - Centro de História de Arte e Investigação Artística, Universidade de Évora. mcmf@uevora.pt
[3] MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, Institute for Advanced and Research, University of Évora, Évora, Portugal. mtfb@uevora.pt
* Correspondence: mtfb@uevora.pt

Abstract: The 2050 European Union's goal of carbon neutrality involves intervening to decarbonise various key sectors in the member states, such as maritime ports. The aim of this study is to develop a methodology of analysis for the port of Sines' landscape, in order to find ways of reducing its carbon footprint through a carbon capture project by its own landscape. The study is based on the data regarding the carbon footprint for which the port administration is directly responsible, as stipulated by scopes 01 and 02 of the Greenhouse Gas Protocol. Next, it is proposed the analysis of the landscape context at three scales (Port jurisdiction, Municipal and Municipal surroundings areas), using GIS tools for land use and occupation parameters and landscape units, as well as landscape planning standards. This characterisation allows the location of ideal zones for implementing emission offsetting measures. The possibility of using vegetation is emphasised as a way of enhancing local ecosystems and reducing the port's carbon footprint, in which it can be chosen based on its ecological and cultural relevance within the context of Sines, with the intention of having a landscape design that is consistent to and active against climate change.

Keywords: Landscape; Carbon Footprint, Decarbonization; Port of Sines; Carbon sink

1. Introduction

The European Union aims to become greenhouse gas neutral by 2050 as a way of slowing down the consequences of climate change. The goal is a central part of the European Green Deal, which aims to achieve efficiency in the use of natural resources, linked to economic development [1]. However, there are many challenges to achieving this goal, which involve the energy transition and the decarbonisation of various sectors.

In order to decarbonise efficiently, it is necessary to thoroughly study the different emitting agents within each activity. Understanding the origins of emissions and the greenhouse gas (GHG) profile associated with activities is a fundamental step in planning the measures that organisations must take to make the energy transition a success. This study, known as the Carbon Footprint, seeks to understand the trail of pollutants derived from their activities, that is, the contribution left in the atmosphere, which consequently aggravates the climate change conditions faced worldwide [2].

Within the European decarbonisation target, an important sector to consider is ports. After all, the complex industrial activity associated with the movement of goods and other services offers many opportunities for significantly reducing GHG emissions. Ports themselves encompass key activities for the economy of the countries and regions in which they are located, because their use is in affinity with the industrial and energy sectors, and they can contain such facilities in their own infrastructures.

Maritime ports, being located in areas that are sensitive to climate change, such as coastal strips, can be seriously affected by rising sea levels and other climatic risks, which can jeopardise the functioning of operations and the performance of the sector. In addition, port facilities are located in a context of transition between terrestrial and marine ecosystems, and are often associated with freshwater bodies such as estuaries and lagoons. These factors aggravate the environmental impact of their infrastructure and can affect the quality of pre-existing natural processes. Therefore, an efficient energy transition and its consequent decarbonisation are viable solutions for maintaining ports and the landscape in which they are located [3].

In order to develop the port sector with environmental responsibility in the face of decarbonisation targets, ports need to be adapted to the landscapes that host them. This can be done through carbon offsetting measures which, by promoting port decarbonisation, also improve the quality of local ecosystems [4]. One of the main compensation measures in the context of decarbonisation is carbon capture, which consists of retaining carbon dioxide (CO_2) from the atmosphere through artificial or natural processes that store it or transform it into other elements [5].

Notably, the oceans are the planet's main carbon sinks, where, through contact between the water layer and the atmosphere, various chemical and biological processes act to capture the element. The oceans alone have captured around 30 per cent of the carbon dioxide emitted by human activities [6]. In addition to marine processes, terrestrial processes account for another important share of carbon capture, accumulating around a third of the carbon emitted by human activities each year. On land, vegetation and soil are mainly responsible for absorbing and retaining the element, where plants capture CO_2 through photosynthesis, transforming it into oxygen and other products [7]. Besides natural cycles, new artificial possibilities for capturing CO_2 have been developed, such as Direct Air Capture (DAC). However, the technology needed for artificial carbon capture is not yet available to operate on the scale required, mainly due to the high cost of implementation [8].

In the port sector, various initiatives have been proposed by different organisations and authorities to reduce their own carbon footprint. The Port of Rotterdam in the Netherlands, for example, proposes storing CO_2 in underwater caves in the North Sea. The programme, called Porthos, is part of the national targets to reduce emissions by 55% by 2030, with 1990 as the base year [9]. Another project that has taken on port decarbonisation is '*Peiraos do Solpor*', in the Port of Vigo, Spain. This initiative proposes intervention in existing port structures by adapting them to the natural environment so that they are integrated into the ecosystem. This is done in order to create habitats that once existed in the area and were replaced by the port facilities. The programme aims to reduce its carbon footprint by capturing CO_2 through improving the quality of marine ecosystems and their associated services [10].

The examples cited above reinforce the contemporary effort to combat climate change, where maritime ports play an important role in decarbonisation and energy transition. Designing landscapes for decarbonisation should be a crucial stage in the development of ecologically and economically balanced societies.

2. Materials and Methods

This work set out to investigate possibilities on port decarbonisation in the context of Sines, on the Alentejo coast in Portugal, where it sought to understand the fundamental role of the landscape as an actor in carbon capture and balance between the forces acting on that territory. Sines was chosen as the case study because it is an important port for the region, where its location concentrates diverse landscape and economic values, and is key to identifying potential intervention techniques for the port landscape, with the intention of developing compensation and carbon capture measures.

The study's methodology aims to analyse the carbon footprint data for the port of Sines, developed as part of the *Agenda NEXUS* study, which applied the principles stipulated by the GHG Protocol and IAPH - Carbon Footprinting to the port of Sines. The methodology used by the study classified emissions into different scopes, based on their emitting activities and the degree of responsibility for emissions in relation to the port of Sines. Therefore, it was chosen to work with data from scopes 1 and 2, as they represent the Carbon Dioxide Equivalent (CO_{2eq}) emissions directly associated with the port activities of the Port of Sines Administration (APS) [11].

After collecting the carbon footprint data, a landscape analysis of the area is proposed based on the 'Site Specific' theory, in which can be carried out on three scales: A local one, in the Area of Jurisdiction of the Port of Sines (AJAPS); an adjacent one, in the Municipality of Sines; an extended one, considering the neighbouring municipalities [12]. The aim of this characterisation is to understand its existing elements, using as a reference the Landscape Units, ecological components and the Land Use Map (COS 2018). This reading is carried out in order to outline and understand the fundamental structure of that landscape.

The next step is the analysis of the legal documents surrounding the area, which determine the basis for its use and occupation, such as the Municipal Master Plan of Sines and of its adjacent municipalities, as well as the maps of areas classified for nature protection. This stage reveals the planning of that landscape and the aspects it considers for its planning and management.

The interpretation of the landscape characterisation maps and their legal zoning plans makes it possible to compare and cross-reference data, using GIS softwares to compute parameters and determine areas with a suitable vocation for implementing land use dedicated to carbon capture.

The following stage involves developing scenarios in which suitable plant species are proposed for each potential zone demarcated, with the aim of obtaining carbon sequestration values based on the vegetation proposed for the three landscape scales. The plant species should be chosen in order of their historical and ecological characteristics, so that their implementation could also reinforce the heritage value of the landscape in which the study takes place.

Finally, the study aims to summarise the results of the carbon footprint of direct emissions from the port of Sines, presenting them in relation to the amount of CO_2 captured by the landscape, as it stands today and as it could be with the proposal presented in this study.

3. Conclusion

This study sought to propose a project methodology that involved aiming for the resilience of the port of Sines landscape, finding in that regional territory and in its natural environment the stimulus to face climate change and take on decarbonisation, through reinforcing its agricultural activities and natural ecosystem services.

In addition, by identifying underutilised and degraded areas, the proposal aims to outline the implementation of new uses that may enhance the region's ecology and natural heritage context. In summary, this work intended to develop a methodology that demonstrates the benefits of the landscape intervention and how this could serve the objectives of reducing the carbon footprint in Sines and its offsetting measures.

Acknowledgments: Content produced within the scope of the Agenda "*NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade*", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).

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Port Decarbonization and Green Jobs: A Pathway to Sustainable Economic and Social Growth

Gonçalo Moura Lestre [1,2] *, Margarita Robaina [1,2] , João Matias [1,2] and Miguel Oliveira [1]

[1] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, Campus Universitário de Santiago 3810-193, Aveiro, Portugal
[2] Research Unit in Governance, Competitiveness and Public Policies (GOVCOPP) , University of Aveiro, Campus Universitário de Santiago 3810-193, Aveiro, Portugal
* Correspondence: goncalo.lestre@ua.pt

Abstract: Port decarbonization is crucial for combating climate change and transitioning to a sustainable economy. This study investigates how decarbonization initiatives at ports may directly promote the creation of green employment, therefore improving environmental sustainability, economic growth, and social welfare. Decarbonization initiatives, such as electrification, renewable energy integration, and enhanced emission control systems, can significantly reduce these emissions. This mixed methods study uses a literature analysis, case studies of major European ports, and stakeholder feedback to determine the economic and societal implications of port decarbonization, with a special emphasis on green employment creation. The study indicates that port decarbonization is critical to meeting global climate objectives while also creating long-term economic and social improvement. Investing in green technology at ports offers a strategic path to enormous environmental, economic, and social advantages, making it an essential component of sustainable development.

Keywords: port decarbonization; green jobs; economic growth; social impacts

1. Introduction

Port decarbonization is an essential component of worldwide efforts to prevent climate change and transition to a sustainable economy. This study looks at how steps to decarbonize ports may directly assist the creation of green jobs, improving environmental sustainability, economic growth, and social welfare. Ports emit considerable amounts of greenhouse gases (GHGs), owing mostly to their reliance on fossil fuels for cargo handling and transportation. Decarbonization requires the use of green technology such as electrification, renewable energy integration, and enhanced emission control systems [1]. Ports contribute considerably to global greenhouse gas emissions.

The principal sources of these emissions are ships, cargo handling equipment, and vehicles working in the port. Decarbonization strategies can significantly cut these emissions. For example, electrifying port operations, integrating renewable energy sources such as solar and wind, and improving emission control procedures can drastically reduce ports' carbon footprint [2]. The application of green technology in ports involves many different processes. Electrification entails switching from diesel-powered equipment to electric alternatives, lowering direct emissions [3]. Renewable energy integration entails placing solar panels and wind turbines on port premises to create sustainable electricity. Enhanced emission control strategies include the use of technologies such as cold ironing, which allows ships to connect to shore power while docked, decreasing the requirement for auxiliary engines [4].

The shift to green innovations in technology at ports not only benefits the environment but also generates significant economic prospects. The demand for qualified workers to develop, implement, and maintain new technologies and infrastructures creates green jobs. For example, cold ironing requires electrical engineers and technicians for installation and maintenance [3]. Ports that engage in green hydrogen generation for fuel transition generate jobs in the hydrogen sector [5]. Thus, incorporating renewable energy sources into port operations creates job opportunities for installation and maintenance of these systems.

2. Materials and Methods

This study applies a mixed methods approach by incorporating a literature review, case studies analysis and stakeholders' feedback. A thorough literature review on the link between ports decarbonization and green jobs is performed. Alternative sources to peer-reviewed journals, such as company and industry reports and policy documents, are also within the framework of the study. Case studies of the main European ports are studied, such as the port of Rotterdam, Antwerp, Hamburg, Algeciras, among others [6]. Policy and legislative documents are also analysed, with a special focus to documents from the European Union and the International Maritime Organization. Through the contact with the relevant stakeholders we aim to collect insights into the challenges and opportunities associated with port decarbonization and green job creation.

All of these collected and analysed data allow us to identify and establish common themes and key factors in order to achieve a successful decarbonization, considering societal impacts, in this specific case, the green jobs creation.

3. Results

The demand for qualified workers to develop, install, and maintain new technologies and infrastructures helps to create green jobs. For example, electrical engineers and technicians are required to build and maintain cold ironing at ports [3]. Furthermore, ports that engage in green hydrogen generation for fuel transition contribute to employment creation in the hydrogen industry [5]. Incorporating renewable energy sources, such as solar and wind power, into port operations also offers jobs for those who build and maintain these systems.

Case studies demonstrate that ports that use sustainable methods efficiently reduce their carbon footprint while also promoting economic growth and employment creation [1,7]. Decarbonizing ports necessitates considerable training and upskilling of the existing personnel to handle new technology and procedures, resulting in long-term job opportunities and growth [8,9]. Green jobs not only help to meet environmental goals, but they also improve the quality of life for individuals and communities [10]. Finally, decarbonizing ports is crucial to achieving global climate goals and creating green jobs. The inclusion of current green technology into port operations not only reduces environmental impact, but it also creates significant job opportunities, contributing to economic and environmental sustainability.

Port decarbonization efforts are predicted to result in considerable reductions in GHG emissions, improved air quality, and better public health. Green jobs in areas like renewable energy, energy efficiency management, and environmental monitoring may help local economies while also providing long-term career prospects. Increased green job possibilities and better public health outcomes are also expected to boost community participation and social welfare.

4. Discussion

Port decarbonization is crucial for achieving global climate goals and creating green jobs. Incorporating current green technology into port operations not only decreases environmental effect, but also creates considerable job prospects, helping to ensure economic and environmental sustainability. This research seeks to explore the economic and societal ramifications of port decarbonization, with an emphasis on green employment development. We investigate how decarbonization operations might strengthen local economies and create long-term jobs by assessing economic advantages such as renewable energy employment prospects and environmental management. The societal advantages, such as better public health, more community engagement, and higher social welfare, highlight the overall benefits of moving to green technology.

5. Conclusions

The findings of this work underline the multiple benefits of port decarbonization. Decarbonization initiatives lead to significantly reduced greenhouse gas emissions from ports, contributing to the achievable of global climate change goals. Such initiatives create economic opportunities through the creation of green jobs, particularly in areas related to renewable energy. Reduced emissions lead to improved air quality, and so, better public health for the surrounding communities. This demonstrates that port decarbonization can aid local economies by allowing them to grow in a sustainable way, while also having a direct and positive effect on social welfare and wellbeing.

Finally, port decarbonization not only supports global environmental goals but also promotes economic and social progress. Future regulations should encourage wider implementation of green technology in port operations to optimize these advantages. Investing in green technology at ports is a strategic decision that may result in significant environmental, economic, and social benefits, making it an essential component of sustainable development.

Funding: This study was funded by the PRR – Plano de Recuperação e Resiliência and by the NextGenerationEU funds at University of Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project nº 53 with the application C645112083-00000059). This work was financially supported by the Research Unit on Governance, Competitiveness and Public Policies (UIDB/04058/2020) + (UIDP)/04058/2020), funded by national funds through FCT – Fundação para a Ciência e a Tecnologia.

Conflicts of Interest: The authors declare no conflicts of interest.

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SMART PORTS, LOGISTICS AND TRAINING

Adil Ait Oualil
Chief Operations Office, Harbor Master Office at Tanger Med Port Authority
Vice-president of the Moroccan Port Officers Association (ACOPM)
Project Leader of New Tanger Med Smart Port Management Information System.
Keynote speaker

Port Call Optimization in Tanger Med

Abstract: Tanger Med, a strategic maritime hub in North Africa, is actively embracing digitalization to enhance port operations and streamline vessel traffic. By leveraging Port Call Optimization (PCO) and Just-In-Time (JIT) strategies, the port aims to minimize vessel waiting times, cut congestion, and improve overall efficiency. The PCO system enables real-time monitoring of vessel movements, optimizing berth allocation, and coordinating various port services. This, coupled with JIT, allows vessels to arrive to the port at the agreed planned time, eliminating unnecessary delays and reducing environmental impact. The integration of these strategies is expected to significantly contribute to Tanger Med's position as a leading global port, attracting increased shipping traffic and boosting regional economic growth.

Keywords: PCO; JIT; Shipping; Maritime; Port Logistics.

1. Introduction

Tanger Med, the largest port in the Mediterranean and Africa, has a key role in global logistics. The port handles substantial volumes of cargo, making it strategically important for international shipping and logistics. Launched in 2007 to be the center of maritime trade for routes between Asia, Europe, Africa and the Americas, the port is taking a holistic approach to Just-In-Time arrival, by viewing it within a wider framework of Port Call Optimization.

2. Concepts and Methodology

Port Call Optimization (PCO) and Just-In-Time (JIT) are two interconnected strategies designed to improve port efficiency and reduce vessel waiting and idle times. PCO involves proactive vessel scheduling, berth allocation, and resource allocation to minimize delays and maximize port throughput. By utilizing advanced algorithms and real-time data analysis, PCO enables efficient planning and coordination of various port operations based on data exchange and collaboration.

JIT strategy in industrial sector focuses on minimizing inventory levels and ensuring that resources are only procured or produced as needed. In the context of ports, JIT aims to synchronize vessel arrivals with port readiness, reducing idle time and congestion. By optimizing vessel movements and coordinating with port call stakeholders, ports can implement JIT practices to streamline operations and improve overall performance. The successful implementation of PCO and JIT requires close mutuality between port authorities, shipping lines, service providers and other stakeholders. Key methodologies include Data-Driven Decision

Making; Advanced Algorithms; Digitalization and Automation and strong Stakeholder Collaboration.

Before 2016, it became apparent to Tanger Med Port Authority (TMPA) that there was a need for transparency on the sequence of vessel movements. TMPA also wanted a system that would ensure safety by mitigating large ships drifting in the narrow port area (the port is located on the Strait of Gibraltar which is a narrow passageway between Spain and Morocco).

TMPA started digitalizing its operations by working with terminals to develop a port global berth plan that provides ships' arrival and departure schedules. This allowed them to create an exchange platform through a Port Community System (PCS) where shipping companies and terminals and other stakeholders can view certain details of the ships at Tanger Med (currently stakeholders can view ships' Estimated Time of Cargo Completion). With the aim to share more information on the timeline of future movements that will include the estimated, requested, planned, and actual time of port calls and how this can deviate using well-known timestamp standards from International Maritime Organization / Global Industry Alliance (IMO-GIA) and the International Taskforce for Port Call Optimization (ITPCO), the berth plan was the foundation for creating a priority management system. This exchange platform (launched in 2018) is a system designed to give priority to vessels based on certain criteria, it allows shipping companies to book a specific time slot for their vessels' movements hours in advance for transit). The TMPA's system provides a provisional priority (number in the queue) and it is updated by actual timestamps communicated by different stakeholders.

TMPA is in the process of implementing Just-In-Time port calls. Through a stakeholder engagement process and trials with major carriers. The carriers have different protocols for vessels' arrival and departure time decisions. This created the need to develop a flexible approach for JIT that would consider all scenarios. For example, one major carrier prefers to have JIT facilitated by the fleet operator who communicates with the captain of the ship. Whenever there is a change in the terminal, the queue, etc., they inform the fleet management by including the new requested time of arrival to port and automatically the fleet management team gets a notification with the new request and can accept the new arrival time or send a new Estimated time. Another major carrier has successfully trailed an approach which engages their local marine agent in decision-making process and data sharing with vessel Captain.

3. Results

TMPA has completed several JIT voyages with multiple major carriers since 2021 starting the process from when the ship departed from the last port of call using different scenarios and is working on creating APIs with major shipping lines and ports to exchange data seamlessly.

Through these port call optimization initiatives, the use of anchorage waiting to berth was reduced by more than 82% and the average time spent in anchorage fell from 17.5 hours in 2017 to 7.3 hours in 2023, while the port call volume was doubled over the same period. Having advanced notice of their movements' priority allows ships to better plan their voyages and port stay, while adjusting their eco-speed.

4. Conclusions

Both PCO and JIT in Tanger Med had shown promising results, with a great impact on safety and environmental protection, however the culture of PCO and JIT must spread even more as to cover all aspects of operations including different types of vessels. The need for a more digitalized processes is key factor into developing a JIT strategy.

TMPA is in the process of developing its own JIT platform in the next coming months, with full insight into using AI and machine learning for forecasts, time-stamps prediction and various scenarios that may affect the operational process, it is the future for the world's maritime trade.

Accurate Estimates of Transshipment Container Dwell Times at Maritime Ports

Eugénio Rocha [1,3], André Lima [3,*], Pedro Macedo [1,3] and Mara Madaleno [2,4]

[1] Department of Mathematics, University of Aveiro, Portugal
[2] Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Portugal
[3] Center for Research & Development in Mathematics and Applications (CIDMA), University of Aveiro, Portugal
[4] Research Unit on Governance, Competitiveness and Public Policies (GOVCOPP), University of Aveiro, Portugal
* Correspondence: andre.lima@ua.pt

Abstract: This work examines dwell time, the period a transshipment container spends at an intermediate port, from offloading to reloading. Accurate dwell time estimates enhance operational efficiency by improving resource allocation, scheduling, and reducing idle times, costs, and penalties. Traditional aggregation and machine learning approaches often yield misleading or inaccurate results due to variability in dwell times. This study proposes a new approach to address these issues, providing precise estimates and richer information for users. By analyzing operational distribution clusters, logistics operators can optimize resource allocation, streamline processes, and boost efficiency, leading to reduced costs, faster turnaround, and greater customer satisfaction. A case study of the Port of Sines is used to illustrate this approach.

Keywords: Transshipment containers; logistics optimization; machine learning.

1. Introduction

Transshipment in maritime ports refers to the process of transferring containers or cargo from one vessel to another at an intermediate port before they continue to their final destination. It often occurs at major or geographically strategic hub ports that serve as central points where cargo is consolidated from various origins and then redistributed to their destinations. It is a cost-effective process that uses larger vessels for the main voyage and smaller feeder ships for regional distribution, allowing flexibility in routing and scheduling, and accommodating changes in demand and unforeseen delays. In this process, the dwell time refers to the period that a container spends at an intermediate port, encompassing the duration from when the container is offloaded from the incoming vessel until it is reloaded onto the outgoing vessel for the next leg of its journey.

Accurate estimates of transshipment container dwell times enhance operational efficiency by enabling better resource allocation and precise scheduling, reducing idle times and increasing throughput. Reducing dwell times lowers storage costs and handling fees, while accurate predictions help avoid demurrage charges. For supply chain optimization, businesses can better manage inventory, avoid overstock and stockouts, and reduce lead times, improving reliability. Reliable estimates ensure timely deliveries, improving customer satisfaction. Efficient port operations reduce congestion and emissions, supporting sustainable practices. Accurate dwell time data informs infrastructure investments and policymaking, enhancing strategic planning. Efficient operations boost competitiveness, attracting more business. Accurate estimates aid in risk management by anticipating delays, allowing for effective contingency plans, and handling disruptions. This study focuses on the Port of Sines, where transshipment movements account for over 50% of all port activities in Portugal.

In the literature, we found some proposed solutions to these issues. In [1], an artificial neural network accurately predicts dwell time of import containers in port container terminals, with factors such as container size, type, discharge day, port of origin, and commodities transported influencing the model's accuracy. In [2], machine learning models, such as gradient boosting, and random forest, effectively estimate dwell times for container vessels at a Busan New Port terminal, improving voyage planning efficiency. Ordinal regression algorithms outperformed supervised classifiers in estimating the dwell time of import containers, reducing reshuffles and mean absolute error modified in 71% of experiments, see [3]. A decision support system to effectively reduce rehandles at port terminals with uncertain inland flows by dwell time-based container (re)positioning was proposed in [4]. Using hidden semi-Markov models [5], which generalize hidden Markov models by explicitly modeling the time spent in each state, allows for a flexible and data-driven estimation of dwell time distributions without strong distributional assumptions. These models excel in learning patterns of normal or frequent dwell times and typically capture the mean value of the corresponding distribution. They are accurate predictors for normal operations but less effective for predicting abnormal or deviant events. Despite other existing methods, the strength of hidden semi-Markov models lies in their ability to handle high variability and capture the mean dwell time behavior.

In this work, we propose to not only estimate/predict the value of the dwell time of a transshipment container but also estimate the representative distribution of the dwell times of its cluster class. Such allows us to understand outlier times, time-space occupancy variations, and probabilities of long stays, all contributing to improving port operation planning. For this purpose, we combine classical machine learning regression techniques with a new distribution-estimation algorithm. The algorithm also splits operations combinations to uncover hidden patterns, correlations, and causal relationships not visible in traditional cross-sectional analyses. This approach allows us to move beyond misleading averages and capture the proper distribution of operational performance, enabling more accurate predictions and informed decision-making.

2. Material and Methods

The case study is based on logs of container movements in the Port of Sines, Portugal, from 2013/Oct to 2023/Sep, with more than 4 million registries. To uncover operational patterns and enhance efficiency in logistics, the algorithmic approach for this work follows three main parts: data processing and distributional clustering (first part), machine learning regression approach (second part), and high-density region identification (third part).

Unlike traditional machine learning approaches focused solely on prediction, this methodology emphasizes a comprehensive understanding of operational distributions. It aims to empower stakeholders with insights into patterns such as bimodal distributions, outliers, and bottlenecks. The process begins with acquiring raw operational data from the *Janela Única Logística* (JUL) platform, followed by comprehensive preprocessing to ensure data quality. Feature engineering techniques extract relevant information, and one-hot encoding with combination generation captures diverse operational characteristics. A clustering-based approach, incorporating filtering, class discretization, and k-means clustering, distinguishes distinct operational patterns. Evaluating clustering results helps select the optimal number of clusters, which are then visualized and interpreted to derive actionable insights. Finally, the aggregated data is exported for further analysis and data-driven decision-making.

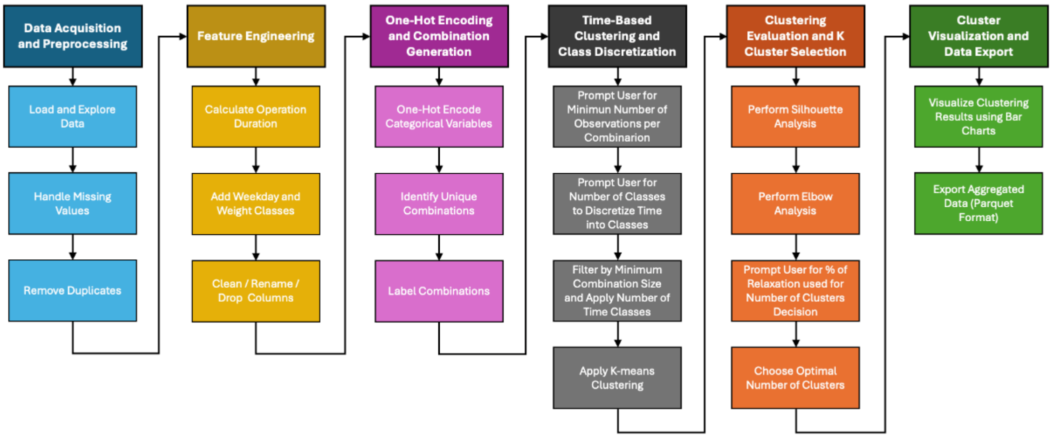

Figure 1 - Algorithm schema employed in this study (different colors represent stages) in the first part. Elaborated by the Authors.

The flow chart in Figure 1 illustrates the algorithm scheme employed in the first part. In further detail, the stages of the first part are described next:

- **Data Acquisition and Preprocessing**: Operational data were sourced from a CSV file (later converted to parquet format, for faster loading) containing records of diverse logistics operations (more than 4 million registries). The initial dataset included timestamps for container movement, container type, container weight, several process references, inbound and outbound information (timestamps, references) and the entity responsible for the container movement. To enhance data quality, missing values and duplicate entries were removed, ensuring a robust foundation for subsequent analysis. Further dataset filtering has been done to analyze container movements of transshipment type.
- **Feature Engineering**: Key features were engineered to capture the temporal dynamics of operations and facilitate pattern recognition. Operation duration and other features were calculated. The dataset was streamlined by removing redundant columns, and the remaining columns were meticulously cleaned and standardized to ensure consistency and compatibility with machine learning algorithms. A unique identifier was assigned to each row to facilitate tracking and analysis throughout the study.
- **Encoding and Combination Generation**: The categorical variables referred to above were chosen to understand the nuances of transshipment operations of containers and, hence, transformed using one-hot encoding. This technique converted each category within a variable into a binary representation, enabling the model to discern relationships between these categories and operational durations. Unique combinations of operational characteristics were identified and labeled, expanding the dataset to encompass a new feature representing each combination.
- **Time-Based Clustering and Class Discretization**: To focus on statistically significant combinations, the dataset was filtered to exclude those with insufficient observations based on a user-defined threshold. The remaining operations were then classified into classes based on the holding time (time spent on the Port, between inbound and outbound date time information), using classes to achieve balanced class distributions. This discretization facilitated the application of the k-means clustering algorithm, which grouped the combinations based on their class distributions. To ascertain the optimal number of clusters, silhouette analysis was conducted to evaluate the internal cohesion and separation of potential cluster configurations.

- **Clustering Evaluation and K-Cluster Selection**: A parameter was introduced (prompt) to allow the user to influence the decision-making process for the ideal number of clusters; this parameter acts as a relaxation value (between silhouette scores, in percentage), in case the user intends to have a higher number of clusters than the recommended by the elbow method result or the silhouette scores achieved.
- **Cluster Visualization and Data Export**: The aggregated data, both at the combination and cluster levels, were exported in Parquet format. This facilitated subsequent in-depth analysis, enabling stakeholders to delve into the specifics of each cluster, identify potential bottlenecks or inefficiencies, and formulate targeted strategies to optimize operational performance and enhance sustainability.

3. Main Results

The results of this analysis, illustrated by Figure 2, reveal a crucial insight into operational performance that traditional metrics using means, commonly used in estimated time durations (as ETA) often obscure. Every average is taken from a set of values, which defines a distribution that might exhibit bimodal (or more) composed shapes, indicating the existence of two (or more) distinct peaks. This is the case of the Cluster in Figure 2. Such suggests that operations do not follow a single average pattern but rather fall into two separate groups, each with its own characteristic time to completion. The average of the distribution is a low frequent value, so when used induces a wrong estimation.

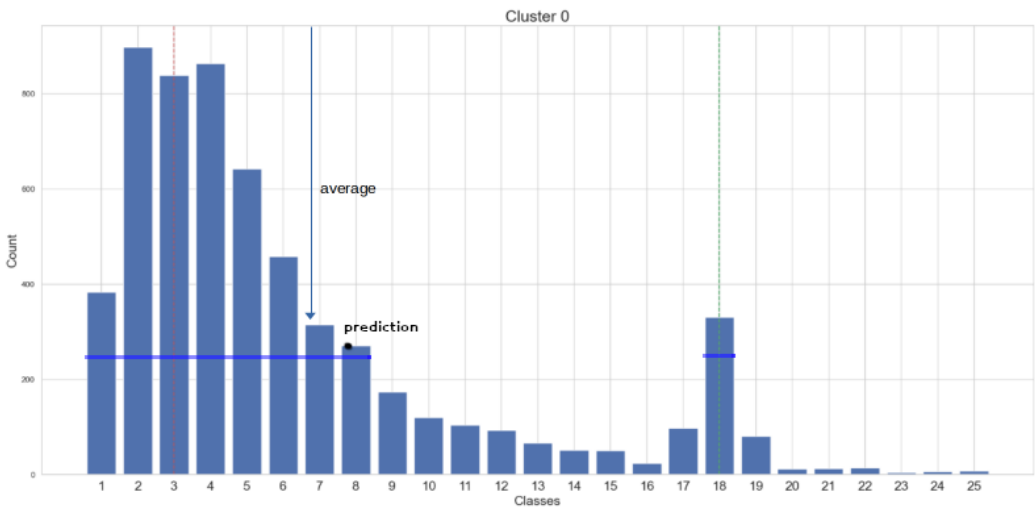

Figure 2 – The frequency plot of Cluster 0, resulting from the approach implemented, shows the position of the (global) average, the two peaks, and the prediction. The prediction class defines a percentile associated with a high-density region, marked in blue.

Then, in the second part, we apply to each cluster a standard machine learning (ML) regression approach to predict the value of the dwell time using the features of the elements that are in the same cluster, by finding the minimum error of each ML model from a set of ML models implemented. In our case, a hyperparameter optimized XGBoost obtained globally the best ML metrics, i.e., root mean square error (RMSE), mean absolute error (MAE) and coefficient of determination (R2), when compared with other regression models such as ridge, random forest, support vector regression, and light gradient boosting machine (LGBM). For space limitations, we omit the details.

Finally, in the third part, using high-density region (HDR) techniques [6], the system for each scenario can enrich the information given to the decision manager, as seen in Figure 3.

Container Plate	Estimate Dwell Time
C1	12.4

Container Plate	Predicted Dwell Time	HDR	Peaks
C1	**15.4**	[10.3,16.1] with p=86%	11.9 with p=89%
		[35.6,37.2] with p=03%	36.4 with p=11%

Figure 3 – Information is given to users by a standard approach (blue) compared with the proposed approach (green), where the values are in days and p=11% means with a probability of eleven percent.

This work represents a significant departure from the norm for logistics managers familiar with relying on estimated values based on average performance metrics. As discussed above, an average duration would fall between two peaks, failing to accurately represent either of the two operational modes within the cluster. This could lead to misinformed decisions based on a misleading representation of reality, influencing (worsening) the container storage planning, influencing (negatively) costs and operation key performance indicators (KPI) and, by extension, the sustainability of the global operations of the port.

4. Conclusions

This study highlights the limitations of traditional summary statistics in logistics management and emphasizes the benefits of a time-centric perspective using machine learning techniques. By identifying distinct clusters with varying time distributions, especially bimodal patterns, it demonstrates the inadequacy of relying solely on averages for decision-making. This approach provides stakeholders with a comprehensive view of operational outcomes, allowing them to tailor strategies to specific clusters, identify bottlenecks, and optimize resource allocation for enhanced efficiency and sustainability. Managers can better allocate resources, optimize workflows, and implement targeted training programs. Additionally, understanding the full distribution of operational durations improves risk assessment and contingency planning. This shift from average measurements to a distributional perspective enables more informed decisions, enhances operational efficiency, and drives greater value across the logistics network.

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Digital transformation of maritime ports: A case of a Smart Pre-Gate in the Port of Sines

Juliana Basulo-Ribeiro [1], Mariana Ferreira [1], João P. S. Silva [2], André Correia [3], Bernardo Macedo [4], Rui Borges Lopes [5], Carina Pimentel [6] and Leonor Teixeira [7,*]

[1] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, 3810-193 Aveiro, Portugal; basulojuliana@ua.pt, marianaisf@ua.pt
[2] Instituto Politécnico de Setúbal (IPS), Setúbal, Portugal; joao.santos.silva@estudantes.esce.ips.pt
[3] Administração dos Portos de Sines e do Algarve (APS), Sines, Portugal; andre.correia@apsinesalgarve.pt
[4] Equipamentos de gestão para aplicações industriais (EGAPI), Braga, Portugal bmacedo@egapi.pt
[5] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), Center for Research & Development in Mathematics and Applications (CIDMA), University of Aveiro, 3810-193 Aveiro, Portugal; rui.borges@ua.pt
[6] Algoritmi Research Unit, Production and Systems Department, School of Engineering, University of Minho, Campus Azurém, 4800 -058 Guimarães, Portugal, GOVCOPP, University of Aveiro, 3810-193 Aveiro, Portugal; carina.pimentel@dps.uminho.pt
[7] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), Institute of Electronics and Informatics Engineering of Aveiro (IEETA), Intelligent Systems Associate Laboratory (LASI), University of Aveiro, 3810-193 Aveiro, Portugal; lteixeira@ua.pt
* Correspondence: lteixeira@ua.pt; Tel.: +351-234370361

Abstract: The increasing digitalization of processes puts pressure on infrastructures to develop reliable and robust information management models, promoting safe, efficient and functional operations. Seaports are key resources for the countries in which they operate and are candidates for digital transformation and the digitalization of their processes. Achieving an efficient entry process at maritime container terminals is a common challenge for all ports. The main objective of this article is to present the entry process at a container terminal using a smart gate approach. To this end, by mapping out the process that can be used to define operations at the gate, the main technologies that will be coupled to the processes to guarantee data collection, as well as the information to be presented, have been identified and presented. In addition, to manage the information coming from this process, the main requirements that will define the exchange of information between the process and those involved (actors) will be defined. This study has practical contributions in that it identifies the flows in terms of process and data inherent in a smart gate, in this case for Terminal XXI at the Port of Sines. On a theoretical level, the contribution is related to increasing knowledge in an emerging area in which, due to its novelty, the literature still has some gaps.

Keywords: Smart Ports; Port Modernization; Requirements Gathering; Systems Modelling; UML; Processes mapping.

1. Background

The efficiency of maritime ports is highly conditioned by their operating costs, availability of services and security [1]. Despite this, due to their strategic location and physical and technological infrastructures, they have a great capacity for innovation, which emphasises their competitive advantage. In this regard, the concept of the smart gate is mentioned in the literature as playing an important role in modernising and consequently increasing the efficiency of seaports [2]. In these, the gates act as a gateway or interface between the activities inside the terminal (international zone) and the outside, with the intervention of various parties such as drivers, customs authorities and security personnel, to ensure the efficient and safe transport of resources and information [3], [4], [5].

The desire to achieve competitive advantage has led to an increase in the demand for more efficient and effective methods for collecting and storing data from organisational processes, giving those who have the best systems greater knowledge of the business. In this sense, it has been crucial to invest in the development of technical and technological solutions, carrying out periodic process evaluations and guaranteeing efficient operations. Particularly concerning seaports, this issue is especially important since, as key points in international trade, they must be managed like the valuable resources they are.

This paper addresses these challenges in one of Portugal's most important maritime ports, the Port of Sines, which is responsible for around 60% of national transactions [6]. Due to the growth in the volume of containerized transactions, increasing the efficiency of terminal entry processes has become a priority to increase the competitiveness of ports. Thus, in general, Gate-IN procedures for containerised goods in ports could benefit from investment in the integration of technology and automation [6], to increase the efficiency of operations associated with terminal entry bureaucracy. Best practice studies to understand how to make this seaport more efficient and profitable, as well as analysis of technologies, digital processes, digitalisation approaches, or even identification of environmental measures, can represent excellent starting points for a digital transformation journey in a port terminal.

This work is in line with these approaches, with the aim being to define a Smart Gate Model in a maritime container port, with efforts at the level of processes, associated technologies and the respective information model to support its operation. In this specific case, the study took place in the port of Sines, more specifically at Terminal XXI. In partnership with the stakeholders of the project (APS, PSA, and carrier companies), the definition and construction of a pre-gate, built upstream of the current gate, was established to implement the Smart Gate concept.

2. Materials and Methods

To achieve the proposed objectives, a methodological approach divided into two parts was used, one theoretical and one practical (Figure 1). On the theoretical side, a study of real cases was carried out based on a benchmarking analysis of the main ports considered to be the smartest [7], and an analysis of the available literature on the subject was conducted [8]. These studies contributed to understanding the state of the art and the main benefits of digitizing processes, as well as identifying the main technologies and infrastructures that could support data collection in terminal entrance operations. On the practical side, and based on the knowledge compiled in the aforementioned studies, the AS-IS process was surveyed, and meetings were held with the main stakeholders and experts in the field of the problem, to understand expectations, challenges and needs that could be materialised into solution requirements. For a better understanding of the whole problem analysis, survey and diagnosis phase, all the development stages were supported by work at the process level, using the Business Process Model and Notation (BPMN 2.0). The processes were represented, mapped and improved as the design of the smart gate solution progressed. Lastly, as all processes involving technology require clarification in terms of data/information exchange, this area, related to information models, was also a fundamental pillar in achieving and designing the most appropriate smart gate solution.

Tools such as BPMN 2.0 and the Unified Modelling Language (UML) were essential for documenting the representations and continuing with the validations around the different meetings that took place throughout the work.

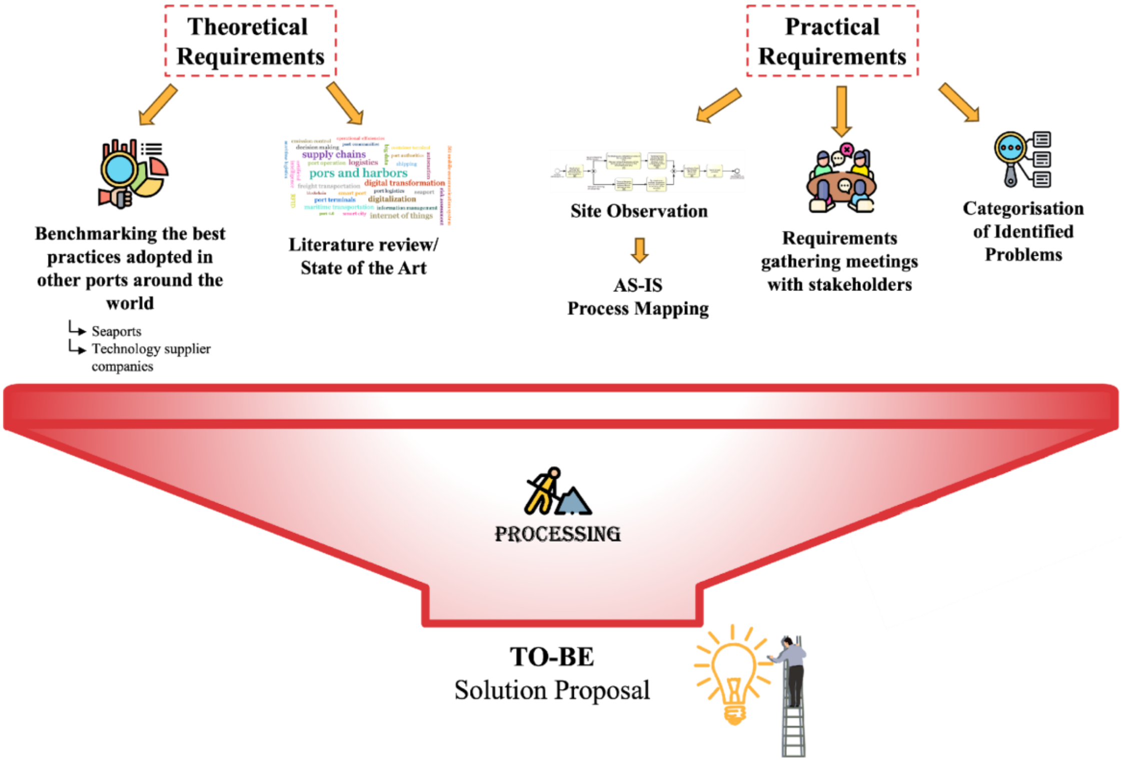

Figure 1. Study methodology.

3. Results

Bearing in mind that this work aimed to define a new process for entering Terminal XXI through a smart pre-gate, several results can be listed: (i) the process model with the technological integration of the new smart pre-gate concept, (ii) the capacity model that gave rise to the physical definition (layout) with a certain number of gates to ensure that the new solution does not create bottlenecks at the entrance at times of greater affluence to the Terminal; and also (iii) an information model to ensure that pre-gate operations guarantee the collection and validation of the data needed for control operations. Before presenting these results, we will first outline the AS-IS process, which represents the current state of entry and exit processes at Terminal XXI, highlighting its limitations.

The current entry and exit process at Terminal XXI has two entry options: with and without prior booking. With an appointment, the driver uses the GAS (Gate Appointment System) to book and obtain authorisation, receiving a PIN that allows automated access if they have a specific card. Without an appointment, the driver must manually validate entry at the terminal gate, causing delays. Both entry and exit processes rely on manual validations and have limitations, such as time-consuming manual checks, limited integration between systems and reliance on access cards or manual signalling, which increases processing time and the risk of errors. Figure 2 illustrates this AS-IS process.

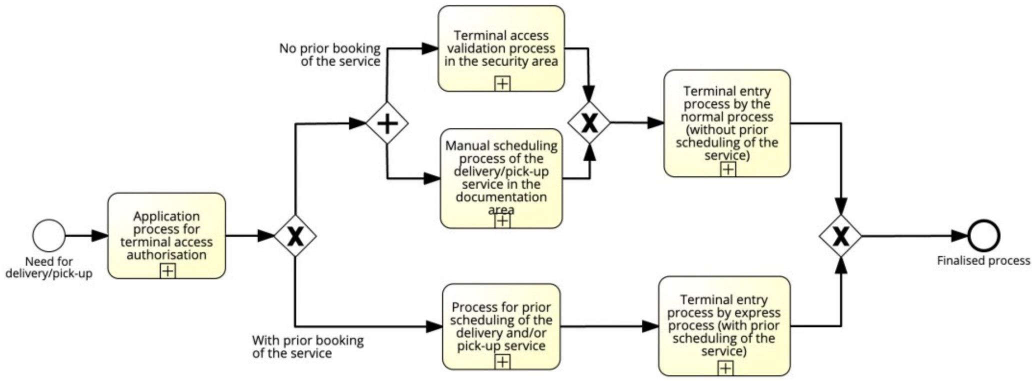

Figure 2. BPMN of the AS-IS process for entering in the terminal.

By addressing these limitations, it becomes possible to create conditions for expanding the entry system to adopt the smart gate concept, decentralising the operations inherent in the associated procedures. As far as checkpoints and controls are concerned, the process took into account 4 checkpoints to ensure the transaction of entries and exits of drivers, vehicles and containers. As mentioned above, to size the pre-gate and avoid constraints at peak times, a capacity study was carried out based on queuing theory. The results of this study, together with the mapping of processes, culminated in the definition of the physical layout of the pre-gate. As far as the processes are concerned, they were mapped using BPMN 2.0, depicting, in addition to the process steps and associated flows, the control points where the data associated with entering the terminal is entered and verified. This representation, albeit at a high level, can be seen in Figure 2.

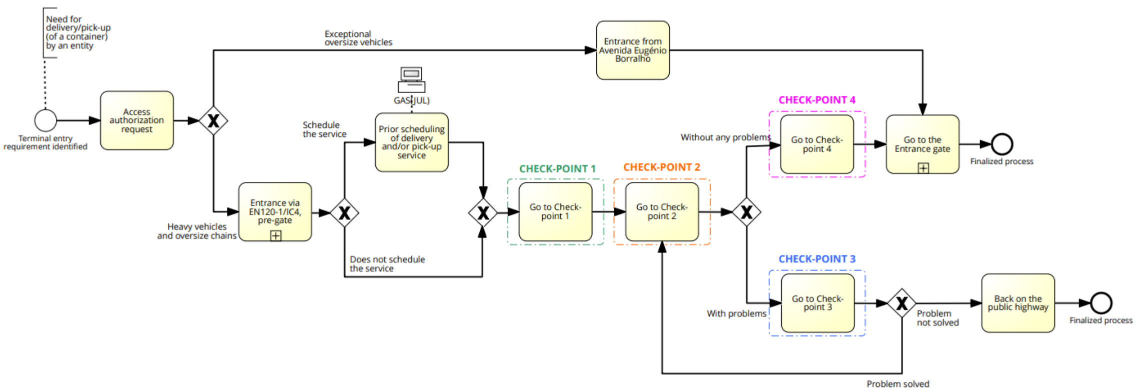

Figure 3. Pre-gate entry process, using BPMN.

In terms of the process, and based on the representation in Figure 3, data entry is carried out either by the driver, at the time of booking, or by the emerging smart gate support technologies identified, namely Optical Character Recognition (OCR). The four control points of the pre-gate process thus facilitate the verification and validation procedures required to enter the terminal:

- At checkpoint 1, the type of vehicle, licence plate number and data on the container(s) are checked;
- At checkpoint 2, the data relating to the driver and also the vehicle, galley and containers are entered and checked.

- Checkpoint 3 is for resolving non-compliant situations and for making an appointment when this has not been done previously;
- At checkpoint 4, the vehicle's license plate is re-verified.

All the checkpoints aim to introduce several layers of security when entering and verifying data, thus ensuring that there is no unauthorised entry into the terminal. The proposed smart gate mainly uses OCR-based devices to read vehicle and container data, but RFID would also be a useful tool.

The use of recognition technologies, context cameras and the automation of the process contribute to a better functioning process, faster data processing and, consequently, more efficient data validation. To study and develop an information model for the terminal entry process via smart gate, it was necessary to define the information requirements. To do this, all the stages of the process were analysed from the point of view of information needs, as well as the associated data input. Table 1 summarises the main stages of the process and the information needs in terms of inputs, outputs and the respective actors.

Table 1. High-level data requirements of the gate entry process

Process phases	Supplier (Actor)	Input	Output	Customer (Actor)
Scheduling	Driver Company/Driver	Vehicle data Driver data Logistic Service data	Scheduling PIN/QR Code	Driver
Check-point 1	LPR Camera ACCR	Vehicle registration Vehicle type Containers data	Route information	Driver, via signaling panel
Check-point 2	OCR portal (LPR, ACCR, ADDR) Driver	Vehicle and Container data Scheduling PIN Driver biometric identification Driver CUP card data	Gate closing order Route information	Driver, via signaling panel
Check-point 3 (problem solving)	Báscula Driver	Vehicle weight Appointment data Driver data Vehicle data CUP card application	Entry permit/deny notification Route information	Driver Driver, via signaling panel Check-point 2
Check-point 4	LPR	Vehicle registration	Entry permit notification Arrival-check Gate opening order	Driver Gate-IN check-point Cancel
Gate-IN	LPR Camera	Vehicle registration Security footage of the vehicle and driver	Entry permit Physical-check Gate opening order	Driver Terminal XXI Cancel

Finally, conceptual models for information exchange were worked out in the form of UML diagrams. Use-case and class diagrams were used, building the models according to the different phases of the process, due to its complexity.

4. Conclusions

In conclusion, this study proposes optimised technological and practical solutions to increase the efficiency, safety and operational sustainability of Terminal XXI. Using the methodology presented above, a future operational model (TO-BE) was detailed with sensors, biometric recognition and data integration to prepare the terminal for future demand and ever-increasing demands and transform it into a more agile and sustainable system by 2033. It was therefore possible to define a structured smart gate entry process, identifying and representing the information exchanges between the port gate entry process and the parties involved/actors. Consequently, and in line with this, the effective implementation of these innovations requires strong collaboration between the various stakeholders and a cultural change to ensure the adoption of the proposed new practices. Therefore, for this to serve as a holistic and replicable model for other ports seeking modernisation and operational optimization, in line with global digitalization and sustainability trends, future work should include fostering a paradigm and cultural shift, which could involve awareness-raising actions, with new practices for using and providing services.

Author Contributions: Conceptualization, J.B.-R., M.F.; methodology, J.B.-R. and L.T.; validation, J.B.-R., M.F., J.S., A.C., B.M., C.P, R.B.L and L.T.; formal analysis, J.B.-R., M.F., J.S., A.C., B.M., C.P, R.B.L. and L.T.; writing—original draft preparation, J.B.-R. and M.F.; writing—review and editing, J.B.-R., M.F., C.P, R.B.L. and L.T..; supervision, R.B.L, C.P. and L.T.; funding acquisition, J.B.-R. and L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the PRR - Recovery and Resilience Plan and by the NextGenerationEU funds at Universidade de Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project no.53 with the application C645112083-00000059). This work was also supported by the research unit IEETA (UIDB/00127/2020), funded by national funds through FCT-Fundação para a Ciência e a Tecnologia.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to private issues.

Conflicts of Interest: The authors declare no conflicts of interest.

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Sizing Study of Pre-Gate Control Checkpoints for Sines Container Terminal

João P. S. Silva [1,*], Bruno Rocha [1], Ana Martins [2], André Correia [3], Ana Mendes [4], Marcela Castro [5] and Tiago Pinho [4]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS-Estefanilha, 2910-761 Setúbal, Portugal; joao.p.silva@esce.ips.pt; bruno.rocha@esce.ips.pt
[2] APS - Administração dos Portos de Sines e do Algarve, SA-Sines, Apartado 16, 7521-953 Sines, Portugal; ana.martins@apsinesalgarve.pt
[3] APS - Administração dos Portos de Sines e do Algarve, SA-Sines, Apartado 16, 7521-953 Sines, Portugal; andre.correia@apsinesalgarve.pt
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS-Estefanilha, 2910-761 Setúbal, Portugal; ana.mendes@esce.ips.pt; tiago.pinho@esce.ips.pt
[5] RESILIENCE – Center for Regional Resilience and Sustainability, Research Center in Business Sciences - Universidade Beira Interior (NECE), Escola Superior de Ciências Empresariais, Campus do IPS – Setúbal, Portugal and; marcela.castro@esce.ips.pt
* Correspondence: joao.p.silva@esce.ips.pt

Abstract: Seaports are essential for international trade and economic growth, driving global market access. Increased container and bulk traffic have boosted trade volumes. Economically, they create jobs, attract investment, and enhance logistics, warehousing, and transportation services [1]. Expanding and modernizing infrastructure with advanced technologies boosts port capacity and efficiency, promoting regional growth and national economic prosperity [2]. The efficiency and right-sizing of port access control points are critical to port operations and impact key areas such as performance, sustainability and community relations. Optimizing the location and efficiency of port gates is essential to improve these aspects. In this context, the accurate dimensioning of a new pre-gate in a container port terminal is crucial to anticipate and mitigate operational bottlenecks and ensure the efficient management of expected growth [3], [4]. The aim of the Port of Sines is to increase operational efficiency, support the local population and improve environmental conditions. This study evaluates the access control points for the new pre-gate infrastructure based on international best practices, literature on smart gates, operational observations at Sines Terminal XXI and interviews with gate operators, drivers and stakeholders.

Keywords: Port; Seaport; Terminal; Processes; Operation; Trucks; Access control

1. Introduction

Restructuring container terminal infrastructure offers opportunities to improve efficiency, profitability and overall success. However, it also brings significant challenges, such as limited land availability, operational issues such as congestion and cargo handling, managing environmental impacts and regulatory compliance [5].

Opportunities include expanding capacity to accommodate future growth, optimizing operations through advanced technologies and automation, improving intermodal connectivity with rail, road and inland waterways, integrating sustainability initiatives and leveraging strategic locations to attract shipping companies and increase competitiveness [6].

Creating new infrastructures that are designed from the ground up to be more efficient is one way to overcome these challenges. By taking advantage of these opportunities, port authorities and terminal operators can develop effective, sustainable and responsive container terminal plans that meet growing global supply chain needs [7].

This study aims to estimate the duration of tasks and determine the optimal number of service points for the new pre-gate by using queuing models, analyzing truck arrival rates and examining driver routines.

2. Materials and Methods

The methodology included researching international best practices for seaport gate management and operations, reviewing literature on smart gates to identify best practices, and conducting direct observations of actual operations at Terminal XXI gate. Interviews with gate operators, drivers, and other stakeholders were also conducted.

The literature review looks at the challenges of digitalization in the container shipping supply chain. It discusses the importance of using various digital technologies at different stages to improve the efficiency and effectiveness of container shipping and discusses the process of digitization, which involves converting physical information into digital formats using tools such as computer systems, e-platforms and blockchain technology. It highlights the collection of new data using technologies in infrastructure that enable the monitoring of processes. It also points out that behaviors and relationships within the supply chain may need to change to take full advantage of digitalization.

The methodology used combined on-site analysis, document analysis, simulation and experimental validation. Several visits were made to an international container terminal to observe and analyze operations. During these visits, the authors collected data on the average time required for the tasks related to the container transportation truck inbound process. Based on the visual analysis, heuristic methods were developed to transfer the observed dynamics, essential for modeling the processes and defining the average execution times, to the access control points of a new pre-gate.

The authors tested and evaluated the coherence of the defined times through simulations and consultations with stakeholders. To test the model, different operational scenarios were created with different numbers of service stations. Experimental validation and data analysis were done to optimize the process. The model was then used to solve the task of determining the number of service stations required to fulfill the tasks of each checkpoint. Overall, the methodology integrated theoretical modeling, data generation, heuristic algorithms and simulation to develop and validate an efficient working model for pre-gate checkpoints in container terminals that enables a comprehensive analysis of terminal operations.

The simulations use queuing theory, which considers the dynamics of customer arrivals, the estimated time to solve access control problems and customer departures. This method was developed based on specific premises related to the awareness of interested parties of the need for new behaviors based on the commitment to pre-scheduling and a set of appropriate rules for the benefit of all stakeholders.

3. Results

The literature review shows that improving port logistics infrastructure and introducing new processes is critical to increase operational efficiency and productivity and to act in a more environmentally friendly way. Poor infrastructure and outdated processes, such as manual access controls, low process automation and manual handling, are sometimes commonplace working practices [5], [8]. These issues can lead to under usage of port capacity, negatively impact port-city relations and affect stakeholders.

Implementing information and communication technology in smart ports increases efficiency by optimizing operations such as ship and container management, reduces environmental impact and improves the accuracy and predictability of resource management. It enables real-time monitoring and rapid response to events, supports data-driven decision making through big data analytics and IoT, and promotes collaboration between stakeholders, increasing the competitiveness and sustainability of port operations [9].

Seaports play a vital role in handling containerized imports and exports, serving as essential hubs in the global supply chain. The competitiveness of container ports is influenced by factors such as service quality, operational efficiency, port facilities, hinterland connections, and location, as perceived by shipping lines. While the responsibility of seaports for managing containerized cargo is implied rather than explicitly stated, their efficiency in handling imports and exports directly impacts their competitiveness in attracting shipping lines and maintaining a strong market position. Overall, the performance of seaports in handling containerized cargo is a crucial factor in determining their competitiveness within the global shipping industry [10].

Several ports are already successfully using physical or virtual pre-gates in their terminals, which are linked to live traffic displays and cameras [11], [12], modern dashboards are designed to reflect operational management best practices, provide regular data and enable better control of terminal activities. Stakeholders have practical and effective tools at their disposal. Examples of physical and virtual pre-gates can be seen at the ports of Vancouver [11], Boston [13], Buenos Aires [14] and Houston [15] they are examples of the use of advanced technologies such as RFID, OCR and automated gate systems to manage the entry of trucks and ensure that all necessary permits and documents are in place before trucks enter the terminal areas. This increases security and improves the efficiency of port operations.

After an overview based on the literature review, we began with an analysis of the specific situation of the port of Sines. Through interviews and observations of truck drivers and the gate workers at the Sines container terminal, we were able to identify delays in accessing the container terminal. Drivers reported that they are often exposed to unfavorable weather conditions and are under stress due to prolonged waiting times. These shortcomings not only affect the wellbeing of drivers, but also have a far-reaching impact on the operational efficiency and overall productivity of the port.

Figure 1 shows the forecasts of the Administração dos Portos de Sines e do Algarve, SA (APS) of the estimated increase in the total number of trucks that will call at the Sines container terminal between 2023 and 2033 and during the peak periods used for the simulations, which are expected to increase from 79 in 2023 to 147 in 2033 [16].

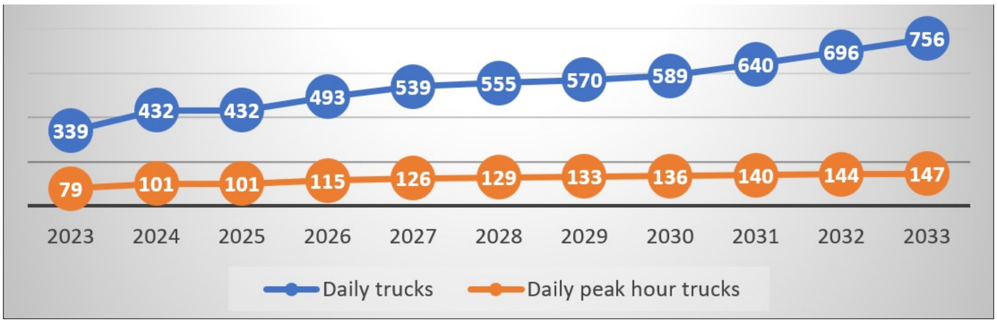

Figure 1. Annual forecast of expected daily trucks and daily peak hours

The new infrastructure is designed to cope with the expected growth by organizing the process in checkpoints for mandatory validations and data collection before the truck drivers reach the main gate of the Sines international container terminal.

Checkpoints sizing

The necessary times for process implementation were determined through direct observations at Terminal XXI and discussions in working groups. This analysis describes principles and simulation results based on queuing theory, considering operational requirements such as parking and task execution time to reduce congestion. It further suggests a flexible, scalable system to adapt swiftly to shifts in demand and initial assumptions.

- **Checkpoint 1** - Automatic reading of the truck license plates and container.

  Cameras with special functions will identify the truck and the container, there are no stops at this checkpoint, so no queues are expected. It is proposed to set up at least two lanes, one of which will serve as a reserve for all eventualities.

- **Checkpoint 2** - Identification and weighing lanes.

  At this checkpoint, a stopping time of 3 minutes was estimated, to achieve this value, tasks common to all drivers were defined, such as identification, authentication and authorization or denial of access to the terminal, as well as the task of collecting and recording the container weight, which is only performed by some of the drivers.

Figure 2 shows that this control point will require 6 lanes by 2025 to accommodate the expected peak hour demand of 101 trucks and should be expanded to 8 lanes by 2033 to handle the expected 147 peak hour trucks. The development of traffic volumes must be monitored regularly until 2033 to determine the time for the gradual expansion to 8 lanes to accommodate the expected increase to 147 trucks in the peak hour.

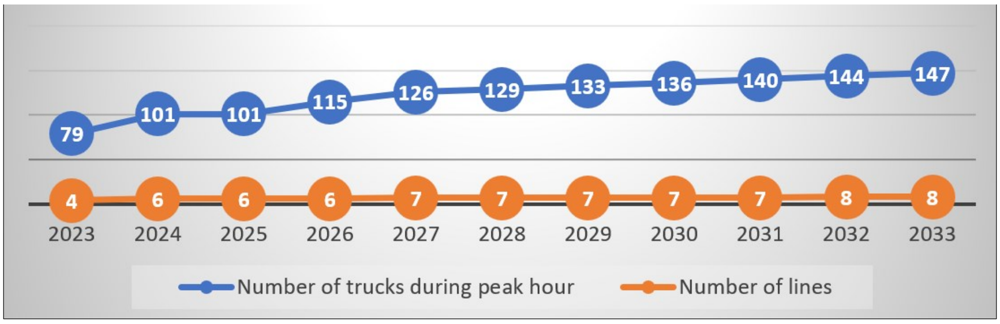

Figure 2. Annual forecast of expected trucks in the daily peak hour and required lanes

- **Checkpoint 3** – Park and problem solver kiosks.

At this stage of the process, identified access control issues must be resolved independently by the truck drivers, parking spaces are provided and situations must be resolved through the us-er-friendly interface kiosks installed to ensure that issues are resolved.

- **Park**.

  To prevent congestion on the surrounding roads, given the limited project area, data gaps in pre-booking rates, seasonal impacts and resistance to change, it is proposed to create 60 parking spaces for standard trucks and 5 for Euro trucks. This allocation is designed to cover at least 50% of peak truck volumes by 2028 if the new process is fully adopted by all stakeholders.

- **Problem solver kiosk**.

  Based on the predicted number of 147 drivers per hour in the peak hour in 2033, additional variables were included in the calculations and simulations, such as the need for some drivers to solve problems at Checkpoint 3, the different profiles and the different levels of support in this process. As a result, it is proposed that 5 service kiosks will be needed by 2033 to solve the access control issues.

- **Checkpoint 4** – Access road to the terminal main gate.

There are no stops at this checkpoint, so no queues are to be expected. If the truck does not have access authorization, the gate will not open, and the driver will have to drive to checkpoint 3 to clear an access issue or leave the pre-gate without entering the container terminal.

4. Discussion

In this study, the needs of the port of Sines were analyzed and various heuristic simulations were tested under different scenarios. It was assumed that the new process should achieve pre-scheduling of almost 100% of terminal visits.

The new infrastructure is intended to solve the problems identified by drivers. If the new process is fully accepted by drivers, most of the problems will no longer have time to develop.

The new infrastructure can enable automatic data collection through IoT devices, which can gather large amounts of data and valuable insights [17]. Regular performance reviews could support timely adjustments and ensure flexibility and scalability in response to market changes [17]

This valuable information can be displayed though a dashboard or live cameras, as is the case with the Port of Vancouver [11] or the Port of Houston [12], making an important contribution to raising the port's profile and improving the performance of the container terminal.

Fluctuations in demand have a significant impact on service quality and represent an important area of future research. Managing customer flow during peak periods and shifting demand to times of lower demand are effective strategies that should be considered.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project nº 53).

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A simulation tool to forecast the behaviour of a new smart pre-gate at the Sines container terminal

Raquel Gil Pereira [1], Rui Borges Lopes [1], Ana Martins [2], Bernardo Macedo [3], and Leonor Teixeira [4,*]

1 Center for Research & Development in Mathematics and Applications (CIDMA), Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT) University of Aveiro, Aveiro, Portugal; araquelgp@ua.pt; rui.borges@ua.pt
2 Administração dos Portos de Sines e do Algarve (APS), Sines, Portugal; ana.martins@apsinesalgarve.pt
3 EGAPI - Equipamentos de gestão para aplicações industriais, Braga, Portugal bmacedo@egapi.pt
4 Institute of Electronics and Informatics Engineering of Aveiro (IEETA), Intelligent Systems Associate Laboratory (LASI), Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, Aveiro, Portugal; lteixeira@ua.pt
* Correspondence: lteixeira@ua.pt; Tel.: +351-234370361

Abstract: Intelligent and flexible logistical systems are crucial in the face of fast technological advancements and global supply chains, particularly at seaports. Automation can maximize port efficiency and adapt to changing circumstances, but port digitalisation is challenging due to the various parties involved and information flows. The port of Sines in Portugal is undergoing digital transformation, specifically about the Smart Gate concept. The port administration and partners have developed a pre-gate, which is being examined for operational procedures, technologies, and information models. The study aims to use simulation to analyse the pre-gate model dynamically and suggest ways to improve processes. The discrete-event simulation model, using Anylogic software, forecasts possible problems and predicts pre-gate behaviour, facilitating ongoing enhancement of pre-gate procedures. With pre-gate construction, a dependable digital twin is to be achieved in the future.

Keywords: port logistics, container terminal, smart gate, truck congestion, simulation, digital twin.

1. Introduction

Over 80% of global goods are transported by sea, necessitating agile ports for timely and safe distribution [1]. The concept of "logistics 4.0" or "smart logistics" refers to logistical activities that are planned and executed intelligently, using new methods to automate decision-making. Data collection and management play a crucial role in smart logistics, requiring progressive technical and analytical efforts to improve data flow and processes [2,3].

Seaports are crucial interconnection points for global supply chains, and the digitalisation of port logistics is an emerging field that has raised interest from academia and industry [4]. Smart ports replace traditional gates with automated processes, allowing entries and exits to be checked with minimal human intervention in smart gates [5]. Automation solutions include lanes with lights and signs, automatic scan of container codes, self-service kiosks, number plate recognition, container damage inspection systems, and biometric driver identification equipment [6]. Smart gates can be more economically and socially advantageous, as they decrease energy consumption during transport, pollution, labour costs, and truck traffic congestion [7].

The port of Sines, one of Portugal's most important ports, seeks to modernize its operations by resolving issues that currently compromise the flow and speed of processes, namely at the road gates. This study aims to simulate the operation of the proposed solution for the new Terminal XXI (or container terminal) road gate, specifically, the future pre-gate, to bring the port closer to a more intelligent and responsive reality.

2. Materials and Methods

The simulation model depicts the pre-gate proposal designed by the port administration, *Administração dos Portos de Sines e do Algarve* (APS). The methodological approach involved identifying and analysing the current capabilities of the gate, sizing up the future situation namely using Business Process Model and Notation (BPMN) to map the processes, and designing a simulation model to portray the pre-gate and test alternatives.

Understanding the problem required gathering essential information in several ways, such as reports and other documentation, videos, meetings, brainstorming sessions with stakeholders, and datasets provided by the entities that manage the terminal. The model was built using a simulation software, Anylogic, to predict system behaviour and identify improvements. Discrete-event simulation (DES) is referred to, in the literature, as a method that is usually suitable for modelling dynamic systems, although it can become less computationally efficient as the complexity of the model increases [8]. At this point, it was determined that DES would be the most appropriate kind of simulation to use. Discrete-event simulations are generated by coding the system in a series of discrete events that happen discontinuously throughout time and have a stochastic interval between them [9].

Like previous related studies that evaluated metrics concerning queue lengths, system timings, and resource utilisation rates [9–14], the primary indicators selected were the throughput, the average time in the system, the average number of trucks in queues, and the resource utilisation. In this study, the number of access lanes to the terminal between scenarios was changed—a parameter that was also altered in the experiments by [10,11]. It has been demonstrated by other authors that it is feasible to decide to modify the scheduling rate [13,14]. Furthermore, to examine the effects of varying attendance, some research examines altering the amounts of cargo to be transported or the frequency of vehicle arrivals [11,12].

Real data was used to determine which probability distributions best fit the trucks' behaviour in terms of the time between arrivals and the process's duration, similar to the methodology followed by [14]. Other input data came from previous capacity studies.

The results from running base and alternative scenarios were used to formulate the main conclusions and contributions.

3. Results

The model considers the four pre-gate checkpoints that drivers must pass through to validate their identity, the cargo, and the truck, as well as the scheduling of the logistical service itself, with checkpoint 2 being the bottleneck. There, the details of the truck and container are recorded photographically, previous bookings are validated, and the driver is identified. The design of the gate will be different to the current situation, with more lanes: seven on the left for drivers who have booked the service and three on the right for the rest. Checkpoint 3 corresponds to a parking area with support kiosks, where drivers go when they need to resolve anomalous situations or when they do not have valid access permission yet. The section of the system that is the subject of this study, specifically the process expected to occur in the pre-gate, is represented in BPMN in Figure 1. The mapping facilitated the design of the logical model in AnyLogic.

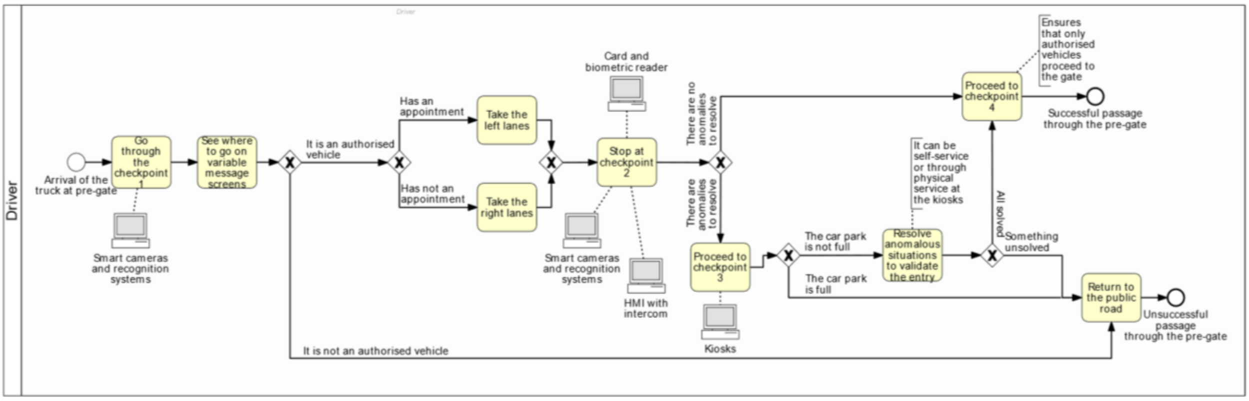

Figure 1. BPMN mapping of the "passage through the pre-gate" process.

The data on truck arrivals were fitted to a probability distribution, resulting in a time between arrivals that follows a Weibull distribution (2.93; 0.742) minutes. The same distribution was assumed for the simulated 16-hour operating period, which ran from 8am to midnight, with no stops during lunch and dinner breaks. It was also hypothesised that the processing times in checkpoints 2 and 3 would be comparable to the existing processes, albeit with reduced durations due to their division. The values were fitted to probability distributions, with outliers removed and values within the second and third quartiles considered. A previous study estimated the average times of three minutes for checkpoint 2 and ten minutes for checkpoint 3. To approximate these values, the distributions were calculated as (1.58 + Weibull (1.51; 1.99)) minutes and (6 + Weibull (4.11; 1.53)) minutes, respectively. Regarding agents, only two were considered: a vehicle and a type of resource for checkpoint 2, whose capacity is zero during the lunch (12 pm - 1 pm) and dinner (8 pm - 9 pm) pauses. The vehicle is a truck, with the most typical length of 16.5 meters; in addition, the speed parameters were defined based on the assumed initial speed of 30 km/h and preferred speed of 20 km/h. Moreover, it was assumed that 25% of the vehicles would arrive at checkpoint 3, meaning that they would not have an appointment or would have an exceptional need to solve anomalous situations. This scheduling rate is in alignment with a target set by the port. Based on actual knowledge of the current process, it is assumed that 1% of vehicles will erroneously proceed to the gate, resulting in their return to the public road. Additionally, 10% of vehicles are assumed to incorrectly proceed from checkpoint 2 to checkpoint 4, despite the necessity to pass through checkpoint 3. A 10-lane scenario was considered, as indicated by the port, based on a forecast of future demand, taking into account the expected future peaks.

Once the parameters and assumptions of the model had been defined, the model was built using Anylogic.

The values of the performance indicators are visible at the end of each simulation run and are easily discernible in the 2D (Figure 2) and 3D animations.

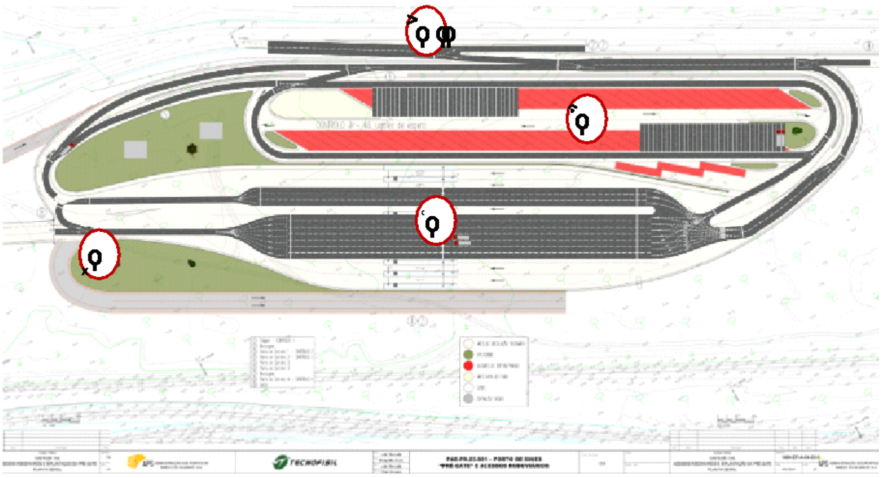

Figure 2. 2D animation of the pre-gate with the checkpoints numbered 1-4.

It is worth noting that, following a period of experimentation and refining, a decision was made to examine 10 replications to achieve 95% confidence intervals (CI) for the designated performance measures within a suitable range.

The 10 active lanes at checkpoint 2 are indicated in the main results as not necessary for the present vehicle arrival rate data. The bottleneck resource will most likely be the lanes leading to checkpoint 4, which in turn still depend on the vehicles that have already passed through checkpoint 3 and are returning to checkpoint 2, given the fact that more vehicles are anticipated in the future. As a result, it makes sense to attempt to reduce the number of active lanes that lead to checkpoint 3 to one. It is also plausible to reduce the number of active lanes heading to the gate, but to a value that does not lead to congestion (two). These changes resulted in the alternative scenario tested, being the results of both base and alternative scenarios in Table 1.

Table 1. Key results of the scenarios.

Scenario	KPI	Mean ± CI
Base	Throughput[1]	273 ± 18.667
	Average time in system (min)	14.835 ± 0.417
	Average number in queue for checkpoint 4	1.24 ± 0.193
	Average utilisation rate for checkpoint 3 (%)	7.7 ± 0.7
	Average utilisation rate for checkpoint 4 (%)	13.6 ± 1
Altern ative	Throughput	276.6 ± 22.826
	Average time in system (min)	18.292 ± 1.188
	Average number in queue for checkpoint 4	2.409 ± 0.503
	Average utilisation rate for checkpoint 3 (%)	24.2 ± 2.4
	Average utilisation rate for checkpoint 4 (%)	48 ± 2.4

The base case led to low resource utilisation rates (7.7% for checkpoint 3 and 13.6% for checkpoint 4), which represents inefficient use, while the alternative scenario was found to be the more reasonable because this number of lanes is sufficient for the system to function properly.

Finally, it should be noticed that the time values acquired might have been biased by the presumption that the pace of vehicle arrivals stays constant for the whole 16-hour simulation. When this is included in these simulations, it becomes evident that when the resources are unavailable, the queues grow significantly.

[1] Throughput can be defined as the number of trucks that are processed, that is to say, the number of trucks that enter and travel the entire route.

In a general way, the study supports the versatility and usefulness of using DES to analyse and improve processes in the context of seaport terminals.

4. Discussion and conclusions

The purpose of this study is to estimate system times, waiting times, and queues by forecasting the behaviour of the pre-gate at Terminal XXI in the port of Sines. A logical model and animation that provided a visual depiction of logistical flows were tested through simulation. The logic of the model has been validated with the help of stakeholder approval and the visualization of metrics, which includes 95% confidence intervals. The reason Anylogic software was selected for the study was its ability to generate discrete-event models with both 2D and 3D animations, specifically for road traffic. Comprehending the prevailing gate procedure and anticipated modifications at the pre-gate was imperative, given the developments in digitalization and automation that define smart gates. Activity sequences were made clearer for the model's design using BPMN. The simulation was based on the most recent layout proposal and figures from previous capacity studies because the pre-gate is not yet in place. Once sufficient lanes were opened, testing a more cautious scenario, with fewer resources, revealed benefits. The ability to simulate complex systems without actual implementations has proven beneficial. The current simulation model for NEXUS could be improved by changing input parameters like vehicle arrival rates to account for different day and year behaviours. The flexibility of testing scenarios is high, and other studies could explore the impact of changes in layout, vehicle routes, scheduling rate, processing times, and agent types, for example. Moreover, although the optimisation of the number of lanes in this study was conducted through experimental and manual means, future research could investigate other techniques, such as Deep Reinforcement Learning, and linear programming. Additionally, extending the indicators to include cost and pollutant emissions analysis could help make informed decisions about pre-gate design.

In the future, with the pre-gate construction, the final goal is to create a reliable digital twin of the pre-gate, making it a useful tool for NEXUS. Digital twins consist of virtual replicas of a physical system, easily adjustable in size and time scale [15]. These can be used for different purposes, such as monitoring, planning, forecasting, and making decisions, free from physical constraints. Therefore, they are related to simulation models since a digital twin can be a simulation model, although a simulation model does not necessarily have to be a digital twin. When a digital simulation model represents a digital twin, it usually integrates a bidirectional exchange of data between the physical entities and their digital counterparts, after collecting data in real-time using sensors and Internet of Things (IoT) devices [16,17].

Author Contributions: Conceptualization, R.G.P, R.B.L, A.M., B.M., and L.T.; methodology, R.G.P; R.B.L., and L.T.; validation, A.M, and B.M.; formal analysis, R.G.P, R.B.L, and L.T.; writing—original draft preparation, R.G.P.; writing—review and editing, R.G.P, R.B.L. and L.T..; supervision, R.B.L, and L.T.; funding acquisition, L.T and A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the PRR - Recovery and Resilience Plan and by the NextGenerationEU funds at Universidade de Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project no.53 with the application C645112083-00000059).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to private issues.

Conflicts of Interest: The authors declare no conflicts of interest.

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Exploring Cloud-Based Access Control for Seaports: Features, Barriers, and Benefits

Maria Sabino [1,*], Liandra Henriques [2], João Silva [3], João Marreiros [3], André Mestre [3], Bernardo Macedo [4], Maria Cabrita [5], Marcela Castro [6] and Tiago Pinho [7]

[1] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; mr.sabino@campus.fct.unl.pt

[2] ISEG - Lisbon School of Economics & Management, Lisbon University, 1200-781, Lisboa, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; l48671@aln.iseg.ulisboa.pt

[3] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; joao.p.silva@esce.ips.pt; joao.marreiros@esce.ips.pt; andre.mestre@esce.ips.pt

[4] EGAPI Technologies, Rua Padre António Vieira, 99, 4710-412 Braga, Portugal; bmacedo@egapi.pt

[5] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal; m.cabrita@fct.unl.pt

[6] RESILIENCE – Center for Regional Resilience and Sustainability, Research Center in Business Sciences - Universidade Beira Interior (NECE), Escola Superior de Ciências Empresariais, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; marcela.castro@esce.ips.pt

[7] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; tiago.pinho@esce.ips.pt.

* Correspondence: mr.sabino@campus.fct.unl.pt

Abstract: Seaports play a vital role in global trade, serving as hubs for the movement of goods. Security and operational efficiency are paramount to the success of these complex logistics environments. Innovative cloud-based access control solutions are increasingly gaining prominence in this context, offering an efficient approach to managing port security and logistics. These technologies are flexible and adaptable to the industry's complex needs. This study aims to explore the features, barriers, and benefits of implementing a cloud-based access control solution in seaports, proposing a new business model that integrates these technologies with the Portuguese Logistics Single Window (Janela Única Logística - JUL). An exploratory literature review was conducted to examine the conceptual framework of cloud computing, access control, port management, security, and business models. This was followed by comprehensive market research and semi-structured interviews with port managers, security experts, and technology providers. The study identified key features and benefits of cloud-based access control systems, including enhanced security, flexibility, and scalability, while highlighting barriers like initial costs and integration challenges. The findings suggest that these systems can significantly improve security and operational efficiency in seaports.

Keywords: Access Control; Cloud Computing; Business Model; Seaports; Security

1. Introduction

Seaports are critical intermodal hubs linking sea and land transportation, requiring robust security measures for multiple stakeholders [1]. Integrated access control systems enhance both security and operational efficiency [2,3], particularly in managing gate throughput and traffic flow [4].

Understanding the distinction between authorization and access control is key to building effective security systems. Authorization specifies access policies and manages permissions, while access control enforces these policies to regulate resource access, improving security and efficiency [5].

NIST Special Publication 800-210 outlines key characteristics of Cloud Access Control, highlighting unique challenges in cloud environments and the need for customized security measures. These recommendations aim to enhance the security and efficiency of access control mechanisms in cloud systems, helping organizations protect data and resources effectively [6].

Implementing robust access control systems is crucial for enhancing port competitiveness and resilience amid new challenges [7]. The maritime industry faces increased cyber vulnerabilities due to digital advancements, reduced human control, and complex systems [8,9]. Addressing these requires tailored cybersecurity for maritime automation, ensuring data confidentiality and integrity [10-12]. Context-aware access control and trust management through semantic alignment can improve security and operational efficiency in port terminals [13, 14]. Blockchain also offers a secure infrastructure, reducing privacy risks and providing immutable logs [15].

This study examines cloud-based access control solutions in Portuguese seaports, analyzing their features, benefits, and implementation barriers. While existing port management research underscores the importance of security, a gap exists around integrating cloud-based access controls, especially within the Portuguese Logistics Single Window. This research fills that gap, proposing an innovative business model for incorporating these technologies.

Integrating access control with other port management tools supports a comprehensive security framework, enhancing sustainability and efficiency by aligning with environmental monitoring, pricing, and regulatory measures [16, 17].

2. Materials and Methods

Research and development activities are pivotal for managing sustainability transitions and driving business model innovations in the maritime industry [18]. To develop this research from an exploratory literature review, we examine the conceptual framework of cloud computing, access control, port management, security, and business models, and its importance within the maritime domain.

Using benchmarking as a strategic tool to better understand customer needs and demands, as well as to obtain insights into market dynamics and emerging trends [19].

After gathering insights from the initial review and benchmarking, we conducted comprehensive market research in the maritime industry to understand the latest trends and technological advancements in access control systems. The market research methodology employed data triangulation, using various data sources to develop an optimal access control solution.

To understand the challenges of access control and security, we conducted four semi-structured interviews with managers from the Planning and Data Analytics (PAD) and Security, Protection, and Environment (SPA) departments of Port of Sines. Using qualitative content analysis, we coded and categorized key themes, gaining insights into expectations, needs, and potential barriers for the new access control system.

3. Results

The main results of this study provide an ample understanding of the potential for a cloud-based access control solution in seaports. This section is divided into three key areas. First, Benchmarking (3.1) involves comparing current access control solutions to identify best practices and gaps. Second, Market Research (3.2) offers an analysis of industry trends, competitive landscape, and potential market demand. Lastly, Insights from Stakeholder Interviews (3.3) synthesize feedback from key stakeholders to uncover practical needs, challenges, and preferences. The results of this study will help in creating a strong and innovative business model for introducing cloud-based access control in seaports.

3.1. Benchmarking

In our research, it has been determined that the successful implementation of access control solutions necessitates a customized approach and a comprehensive understanding of the environment and organizational characteristics. This customized approach encompasses adherence to legal regulations and industry best practices. Companies provide on-site, cloud-based, or hybrid solutions, offering flexibility for organizations. Clients have the option to choose between vendor-owned or client-owned hardware, and various identification and authentication options are available.

The use of biometric data raises significant privacy concerns, necessitating additional measures to ensure compliance. A tailored, adaptable, and secure approach is key to ensure the efficacy and integrity of the system. Cloud-based access control encompasses authentication, access, management, and hardware. It offers advantages such as lower initial costs, intuitive user experience, remote monitoring capability, and cybersecurity considerations. Different pricing models are available to accommodate various organizational needs.

3.2. Market Research

We conducted market research in the logistics industry to understand trends in access control systems, analyzing competitor activities and technological advancements. Our study included examining the Open Data Platform (ODP) in the maritime industry, along with 10 platforms from other sectors to identify applicable cross-domain features.

The relationship between open data and access control balances transparency with security. While open data initiatives provide public information to foster innovation and accountability, access control safeguards sensitive information by restricting data modification to authorized users.

From 22 operating systems identified in the port industry market, we established an evaluation matrix comparing key parameters. Table 1 presents these parameters and their scope:

Table 1. Key Parameters for Market Evaluation.

Key Parameters	Description
1. User types	The providers offer support for different types of users, including home, office, and industrial environments.
2. Authentication	Various authentication methods such as multi-factor authentication, app integration, QR codes, smartwatches, and different biometric options such as fingerprint and facial recognition.
3. Deployment Models	All providers support the cloud model, allowing remote access and scalability. Some providers also support the hybrid and on-premises model.

Key Parameters	Description
4. Access and management	The presence of mobile and desktop applications suggests that these providers prioritize remote access management and ease of use. All support remote permissions and unlimited access per unit, which is essential for large-scale environments like ports. The personalized access, as seen with some providers, allows companies to control the level of access for each individual or group, facilitating compliance with specific regulations and ensuring security.
5. Features and operability	All providers support CCTV and cloud-based cameras, with some offering two-way communication (intercom) and real-time notifications; AI, GPT and Automatic Backups; Blocking and Integration with APIs;
6. Pricing	Free versions and volume-based licensing; Volume-based licensing

The table provides a comprehensive analysis that can assist decision makers in choosing the most appropriate access control solution based on their specific needs. For a port environment, where safety and operational efficiency are crucial, the expected results from analyzing this table include:

- Selecting a More Secure Solution: By identifying providers with greater support for biometric and multi-factor authentication, the overall security of the port environment can be strengthened.
- Improved Operational Efficiency: Choosing providers that offer integration with APIs, mobile apps, and remote control can streamline operations, reducing wait times and access bottlenecks.
- Adaptation to Scope and Scalability: Port environments can benefit from opting for providers that support cloud and hybrid options, allowing for scalable deployment that adapts to growth needs.
- Optimized Cost-Benefit: With a choice of pricing models and trial versions, it is possible to carry out a gradual implementation and measure the return on investment before committing to the full solution.

This analysis highlights each provider's strengths and limitations, supporting decisions that align with port facility security and efficiency objectives. Further selection will consider additional economic, marketing, and connectivity factors.

3.3. *Insights from Stakeholder Interviews*

Based on interviews with stakeholders, several key pain points and potential gains were identified to shape a value proposition that aligns with the specific needs and challenges in the port environment.

Stakeholders highlighted issues such as biometric difficulties, high personnel turnover, entry delays, suspicious behaviour, challenges with crew access control, and card reader malfunctions. The complex port setting presents additional challenges due to different entrances and exits in distinct zones, and the need for control over entry permissions. Furthermore, there are personal and structural limitations affecting access.

The proposed gain creators to address pain points include proactive professional training aligned with port security standards, SAP and API integration for enhanced functionality, and a 24/7 operational system for unrestricted access. Streamlining appointments via kiosks or apps, eliminating manual controls with non-compliance modules, adding video intercoms and individual access controls, and providing alternatives to biometrics and personalized reception cards aim to enhance security and efficiency in port access management.

These insights will guide our future efforts in refining the value proposition and developing a new business model to ensure that our solutions fully meet the needs and expectations of the users.

4. Conclusion

The implementation of cloud-based access control solutions in seaports presents opportunities to enhance security and operational efficiency. Our study identified that these systems improve security through advanced authentication methods, real-time monitoring, and streamlined access permission management, while offering the flexibility to adapt to dynamic port operations.

Our research also highlights the importance of a tailored approach that aligns with specific organizational requirements and legal regulations. The comparative analysis of various access control providers underscores the necessity for customized solutions that integrate seamlessly with existing port infrastructure while meeting stringent data privacy standards. Additionally, the study underscores the value of integrating access control systems with other port management tools and technologies, fostering a comprehensive security framework that enhances both operational sustainability and efficiency.

The market research and benchmarking activities conducted in this study provide valuable insights into the latest trends and technological advancements in access control systems. The findings suggest that cloud-based solutions, when properly implemented, can offer a strategic advantage by reducing initial costs, improving user experience, and enabling remote monitoring capabilities. These advantages make cloud-based access control an appealing choice for seaports aiming to bolster their security measures and operational effectiveness.

Our study also addresses the critical relationship between open data and access control, emphasizing the need to safeguard sensitive information while promoting transparency and collaboration. The use of semantic technologies and context-aware access control mechanisms further enhances the precision and efficiency of these systems, ensuring that only authorized individuals can access specific areas and information.

In conclusion, the studies conducted have provided valuable insights into the implementation of cloud-based access control solutions in seaports. These findings highlight the potential benefits, including enhanced security and operational efficiency, while also addressing the barriers to successful implementation. The comprehensive understanding gained from this research will guide our future efforts in refining the value proposition and developing a new business model. This will ensure that our solutions fully meet the needs and expectations of the users, ultimately contributing to the competitiveness and resilience of seaports in the face of evolving challenges.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53)

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Essential Competencies in Maritime and Port Logistics: A Study on the Current Needs of the Sector

Luís Lopes [1,*], João Lemos Nabais [2], Claúdio Pinto [3], Vitor Caldeirinha [4] and Tiago Pinho [4]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS – Setúbal, Portugal; luis.lopes@ips.pt;
[2] IDMEC - Instituto Politécnico de Setúbal, Marketing and Logistics Department, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; joao.nabais@esce.ips.pt;
[3] APS - Administração do Porto de Sines e Algarve – Sines, Portugal; claudio.pinto@apsinesalgarve.pt;
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; vitor.caldeirinha@esce.ips.pt; tiago.pinho@esce.ips.pt;
* Correspondence: luis.lopes@ips.pt

Abstract: This study explores the core competencies in the maritime logistics and port management sector, addressing competency needs through a mixed-methods approach. The research combines benchmarking with leading universities in the maritime industry, interviews with 15 industry stakeholders representing diverse profiles, and a detailed curriculum analysis. Technical, management, and interpersonal competencies were identified and synthesized into a competency matrix, including strategic decision-making, operations management, data analysis, flexibility and adaptability, teamwork collaboration, and customer understanding. The findings contribute to existing literature by providing a comprehensive analysis of competency requirements, emphasizing the importance of continuous collaboration between academia and industry to ensure that educational programs align with sector demands. Despite the limited sample size and the absence of a longitudinal analysis, the diversity of the interviewed stakeholders offers a broad perspective on the critical competencies within the national maritime sector. Future research should explore the role of innovation and emerging technologies on the shaping of professional competencies. This work aims to contribute to the development of training programs that better equip professionals for an increasingly competitive and dynamic industry.

Keywords: Maritime and port Logistics; Essential Competencies; Professional Training; Educational Benchmarking; Stakeholders

1. Introduction

Maritime logistics and port management are integral to the global economy, serving as essential pillars for international trade and the efficiency of global supply chains. The sector's increasing complexity and dynamism demand that professionals possess advanced technical, management, and interpersonal competencies to effectively address emerging challenges and capitalize on new opportunities. The impact of globalization, coupled with rapid technological advancements, has heightened the need for skilled professionals capable of adapting to these changes. In this context, identifying and fostering the competencies critical for professional success in the supply chain is essential [1], as is the development of training programs tailored to the sector's evolving needs [2,3]. Ongoing professional development and lifelong learning are vital for ensuring both competitiveness and sustainability within the maritime sector.

This study offers a comprehensive analysis of the competencies required in maritime logistics and port management, examining both current and future demands. It aims to empower professionals to navigate shifts in the sector effectively [4]. Using robust research methodology, including benchmarking with leading universities, interviews with industry stakeholders, and comparative curriculum analysis, the study identifies and categorizes essential competencies. This process guides the development of specialized training programs designed to equip professionals with the skills necessary to thrive in an increasingly competitive landscape [5,6].

The primary objectives of this study are: i) to identify and categorize the essential technical, management, and interpersonal competencies needed in the maritime and port logistics sector; ii) to benchmark curricula from national and international reference universities to identify competencies and skills addressed; iii) o conduct interviews with relevant stakeholders in the national maritime sector to understand competency needs and expectations; iv) to develop a competency matrix to guide the creation of specialized training programs aligned with both current and future industry needs; and v) to assess the relevance of these competencies to ensure that proposed training programs meet market demands effectively.

2. Materials and Methods

To achieve the objectives of this study, a mixed-methods approach was employed, integrating both quantitative and qualitative research methodologies [7,8,9]. This comprehensive approach was designed to ensure the robustness and replicability of results, providing a detailed foundation for identifying essential competencies in the maritime logistics and port management sector.

The first phase involved benchmarking with leading national and international universities in the maritime industry, as detailed in Appendix A (Table A1), which includes a list of the institutions analyzed [10,11,12,13]. This benchmarking phase focused on curriculum analysis, mapping key technical, management, and interpersonal competencies covered across various training programs [14–35]. Through this curriculum mapping, competencies were identified by comparing courses to determine the skills emphasized in top-tier programs. This benchmarking phase was instrumental in establishing a solid foundation for recognizing industry-valued practices and competencies in maritime logistics and port management, forming a core element for identifying competencies essential to the sector. The curriculum details and specific competencies mapped within these programs are further presented in Appendix A (Table A2).

The second phase involved conducting interviews with sector stakeholders. An interview guide was created to ensure consistency in data collection from relevant stakeholders in the national maritime sector. The characterization of the interview sample, as detailed in Appendix B (Table B1), highlights the diversity of profiles and breadth of perspectives included in the study. A representative group of 25 stakeholders was invited to participate, with 15 respondents completing the interviews, resulting in a response rate of 65.22%. This diversity in participant profiles provided a broad perspective, enriching the study's insights into industry needs and challenges. The interviews facilitated a deeper understanding of the competencies required by the sector, emphasizing the skills deemed essential for professionals. This process was rigorously and systematically structured to guarantee consistency and validity in the information obtained.

Data analysis employed a 5-point Likert scale, with ratings ranging from "Not Important" (1) to "Extremely Important" (5). Each category (technical, management, and interpersonal) included a defined set of 22 competencies identified through benchmarking, which were then systematically evaluated by interview participants. Competencies receiving a rating of 4 or higher were classified as high-relevance competencies, ensuring that the analysis concentrated on skills critical to the sector. These competencies were subsequently structured into a competency matrix, as presented in Appendix B (Table B2), which serves as a foundation for developing specialized training programs aligned with industry requirements. This structured approach allowed for an accurate quantification of the importance attributed to each competency, essential for pinpointing the competencies most relevant to the maritime and port logistics sector.

3. Results

The results of this study revealed a structured set of competencies that stakeholders consistently identified as essential for success in maritime logistics and port management, consolidated in the competency matrix presented. This matrix provides an organized perspective on core competencies across technical, management, and interpersonal domains, aligning with the multifaceted demands of the sector. Figure 1 presents an analysis of the six competencies that received the highest ratings in the study, selected from a sample of 27 competencies classified as high relevance by stakeholders, underscoring their critical role in the sector's success.

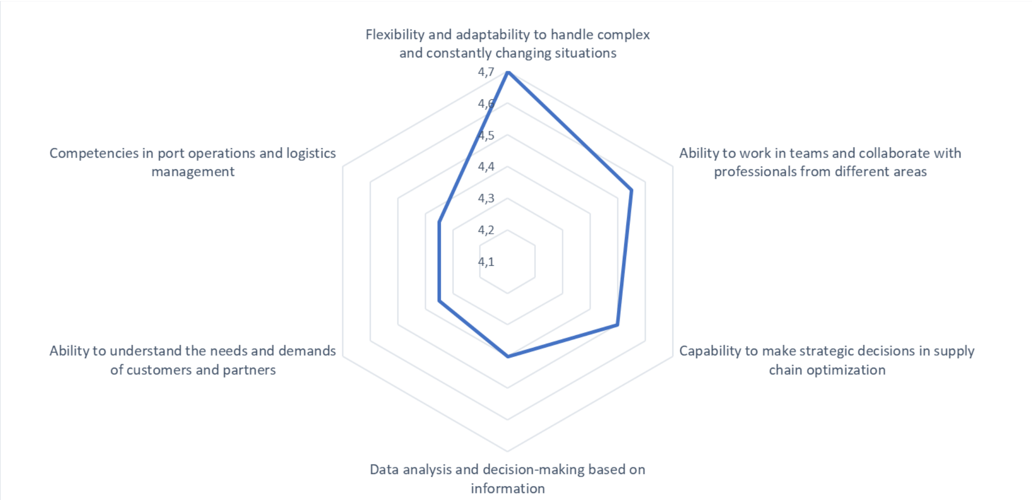

Figure 1 Most relevant competencies identified in the study

Among the competencies identified, "Strategic decisions in supply chain optimization" was highlighted as one of the most critical, reflecting the need for managers who can streamline processes, reduce costs, and enhance efficiency. This competence is essential at the management level, in an environment where the margin for error is minimal and operational efficiency is vital for competitiveness. Additionally, "Data analysis and decision-making based on information" was also highly valued, emphasizing the growing importance of leveraging data to make informed decisions and drive continuous operational improvement. The ability to interpret and utilize large data volumes to predict trends and identify improvement opportunities is increasingly crucial in today's context.

Another highlighted competency, this time on an interpersonal level, was "Flexibility and adaptability to handle complex and constantly changing situations." This skill is essential for effective management in a sector characterized by uncertainty and the need for swift responses to regulatory, climate, and market changes. Professionals must be able to quickly adjust strategies and processes to maintain resilience and operational efficiency.

The "Ability to work in teams and collaborate with professionals from different areas" was also emphasized, underlining the importance of interdisciplinary collaboration and effective communication among multifunctional teams. In environments where the integration of different specialties is crucial to operational success, the ability to work well with others is invaluable.

Moreover, the "Ability to understand the needs and demands of customers and partners" was seen as vital for customer satisfaction and building long-term relationships in the sector. The ability to listen, understand, and respond effectively to client needs is fundamental to building a solid reputation and sustaining successful partnerships.

Finally, "Competencies in port operations and logistics management" was considered central to ensuring an efficient and uninterrupted cargo flow, making it a critical area of training for technical professionals in the sector. This competency encompasses everything from warehouse and terminal management to transportation coordination and cargo handling, ensuring each stage of the supply chain operates smoothly and efficiently.

4. Discussion

This study provides a comprehensive analysis of the essential competencies in maritime logistics and port management, culminating in the development of a competency matrix (presented in Appendix B, Table B2). This matrix serves as a valuable tool for designing targeted training programs that address specific sector needs, enabling the preparation of new professionals to effectively confront industry challenges and seize emerging opportunities.

The findings of this study are consistent with prior research, which emphasizes the importance of strategic decision-making, data-driven approaches, and robust interpersonal skills in the logistics and port management fields [1,3,4]. However, this research extends existing knowledge by offering a structured framework that not only identifies these key competencies but also integrates them into educational programs, with particular emphasis on technical skills tailored to maritime operations.

A key contribution of this study is the identification of competencies that are critical for both immediate operational needs and long-term sector sustainability. For example, the focus on data analysis and strategic decision-making underscores the increasing demand for professionals who can thrive in a digitalized, complex environment. Meanwhile, interpersonal skills such as adaptability and collaboration highlight the importance of resilience and effective teamwork within dynamic operational contexts.

Future research could focus on the practical application of these competencies in educational settings, examining their impact on professional preparedness. Additionally, further studies could explore the role of innovation and emerging technologies, such as artificial intelligence and automation, in shaping the evolving competency landscape and their potential to influence future sector requirements.

5. Conclusions

This study represents a significant advancement in understanding the competency needs within Portuguese maritime and port logistics. The competency matrix developed here, as presented in Appendix B (Table B2), not only highlights the critical competencies identified by stakeholders but also provides guidance on the key areas to focus on when training new professionals, preparing them to meet the sector's specific demands and challenges.

Based on the findings, it is recommended to establish advisory boards or strategic partnerships between academia and industry to ensure continuous updates to training programs, keeping them aligned with industry developments and emerging needs. Such ongoing collaboration is essential to ensure that educational programs remain relevant and responsive to real-world advancements, while also fostering a culture of innovation within the sector, enabling it to swiftly adapt to changes and uncertainties in the global market.

Through collaboration with stakeholders throughout this study, we have not only identified the current needs of the sector but also projected future scenarios and case studies, which are critical for the effective training of students and professionals. We believe that the results of this work represent a key step in preparing professionals for the challenges in maritime and port logistics, encouraging a lasting partnership between academia and industry in a strategically vital sector for the country.

Funding: Content produced within the scope of the Agenda "Nexus – Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n. º53).

Appendix A

Table A1. National and international universities in the maritime industry.

Country	Institution	Program
AU	The University of Sydney	Master of Marine Science and Management
BE	University of Antwerp Faculty of Business Economics	Maritime Transport Management
DK	Copenhagen Business School - CBS	Executive MBA in Shipping and Logistics: the Blue MBA
EC	Universidad del Pacifico Escuela de Negocios Ecuador	Gestión Marítima y Portuaria - GEMA
FR	KEDGE Business School	MSc International Trade and Logistics
GR	Athens University of Economics and Business	MSc in International Shipping, Finance and Management
GR	Alba Graduate Business School at the American College of Greece	MSc in Shipping Management
HK	The Hong Kong Polytechnic University	MSc in International Shipping and Transport Logistics
IE	University College Cork	MSc Coastal and Marine Management
JP	Kobe University - G. School of Business Administration	Master of M.S.T. - Maritime Management Sciences
NL	Erasmus University Rotterdam	Masters in Maritime Economics & Logistics
NZ	The University of Auckland	Master of Marine Studies
PT	Nova School of Law / Nova SBE	Mestrado em Direito e Economia do Mar
PT	Nova School of Science and Technology	Mestrado em Logística Marítima
PT	Instituto Politécnico de Viana do Castelo	Pós-Graduação em Logística e Transporte Marítimo
PT	ISEG Executive Education	Pós-Graduação em Shipping and Port Management
PT	Escola Superior Náutica Infante D. Henrique	Pós-Graduação em Gestão Portuária & Logística
SG	Nanyang Technological University (NTU)	MSc in Maritime Studies
SG	National University of Singapore	LL.M. Maritime Law
SI	Faculty of Maritime Studies and Transp. of Ljubljana	Master in Maritime Studies
UK	City University of London - S. of Mathematics, C.S.E.	MSc Maritime Operations and Management
UK	Cardiff University	MSc Maritime Policy and Shipping Management
USA	Texas A&M University	Master of Maritime Administration & Logistics

Table A2. Mapping competencies in training programs.

ID	Technical competencies	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	Knowledge of maritime and port regulations and legislation	X			X	X	X		X		X		X	X	X	X	X		X	X	X	X		
2	Competencies in port operations and logistics management					X	X		X			X			X	X	X	X	X			X	X	X
3	Proficiency in planning and managing port terminals		X	X				X	X			X			X	X	X	X	X				X	X
4	Knowledge of maritime transport logistics and cargo handling operations	X		X	X	X	X		X			X			X	X	X	X	X		X	X	X	X
5	Risk management and safety in port operations						X	X	X	X		X		X		X	X	X	X	X		X	X	
6	Competency in Technologies Applied to Maritime and Port Logistics		X	X				X			X	X			X		X	X	X			X		
7	Competency in quality management systems and certifications applied to maritime logistics	X	X	X			X	X	X	X	X	X	X			X	X	X			X	X		X
8	Expertise in reverse logistics and waste management in port operations						X		X		X	X				X	X	X	X				X	X
9	Inventory management and stock practices in port terminals											X			X	X	X	X						
10	Mastery of container operations and cargo handling technologies		X	X	X	X	X	X	X		X	X				X	X	X	X		X	X	X	X
11	Skills in contract and supplier management in maritime logistics		X	X	X	X	X	X	X			X		X			X			X	X	X	X	X
12	Proficiency in multimodal logistics operations (maritime, land, and air)		X	X	X	X	X	X	X		X	X				X	X	X	X		X		X	X
13	Knowledge of customs management and import/export procedures		X	X	X							X		X	X					X				
14	Knowledge of warehousing and distribution logistics					X									X			X				X		
15	Ability to analyze and implement automation solutions in port processes		X									X			X	X	X							
16	Knowledge of handling and storage practices for hazardous cargo				X											X		X			X			
17	Ability to analyze and optimize logistical and operational processes		X		X	X	X		X		X	X		X		X	X	X	X	X	X	X	X	X
18	Management of Sustainable Projects	X	X	X	X					X	X	X	X	X			X			X		X		X
19	Digital Transformation		X	X							X	X					X				X			
20	Mastery of Circular Economy practices	X	X	X	X					X	X	x	X		X	X	X		X					X
21	Competency in Renewable Energies in Port Environments		X	X						X	X	X		X								X		
22	Management of Renewable and Sustainable Energy Projects		X	X						X	X	X	X	X								X		X

ID	Management competencies	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	Leadership and team management skills	X	X	X	X	X						X	X	X	X	X	X			X		X	X	X
2	Capability to make strategic decisions in supply chain optimization		X	X		X	X	X	X		X	X			X	X	X						X	X
3	Project management in the maritime logistics field			X		X	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X
4	Data analysis and decision-making based on information	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
5	Ability to innovate and implement technological solutions in maritime logistics		X	X						X	X	X	X	X			X				X	X		
6	Negotiation skills and management of strategic partnerships and commercial contracts		X	X	X	X	X	X	X		X	X		X	X	X	X		X	X		X		
7	Leadership and management of cross-functional teams		X	X	X	X			X	X	X	X	X				X	X		X			X	X
8	Knowledge of financial and budget management for port operations		X	X		X	X		X			X			X	X	X		X	X			X	X
9	Ability to develop marketing strategies and promote port services			X				X	X			X				X	X	X	X			X	X	X
10	Resource and equipment management in port terminals		X					X	X			X				X	X	X					X	
11	Crisis management and contingency planning in port terminals						X		X							X	X	X				X	X	X
12	Ability to conduct economic and financial feasibility analysis of logistics projects		X	X	X	X	X	X	X		X	X			X	X	X	X	X				X	X
13	Knowledge of sustainable supply chain management and ESG practices		X	X						X	X	X		X	X	X	X		X	X			X	X
14	Ability to lead teams in emergency situations and port safety						X			X			X			X	X	X				X		
15	Conflict management and resolution of operational issues				X		X		X	X			X				X	X	X		X	X	X	
16	Competency in fleet management and optimization of maritime routes		X	X	X	X	X	X	X		X	X				X	X	X	X		X	X	X	X
17	Knowledge of disruptive technological trends in the maritime logistics sector		X	X	X	X		X			X	X	X				X				X			
18	Skills in data analysis to improve operational efficiency		X	X	X	X	X	X	X		X	X	X			X	X	X			X	X	X	X
19	Ability to develop strategic partnerships with companies and government entities								X				X			X	X							
20	International awareness		X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X		X	X	X
21	Energy Transition Strategies		X	X						X	X	X	X	X					X		X	X		
22	Risk and Opportunity Management in the Green Transition		X	X	X					X	X	X	X	X	X				X	X	X			X

ID	Interpersonal competencies	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	Effective communication skills with various stakeholders			X	X							X	X	X	X	X	X			X		X	X	
2	Ability to work in a team and collaborate with professionals from different fields	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			X		X	X	
3	Flexibility and adaptability to handle complex and constantly changing situations	X	X	X		X				X	X	X	X	X	X	X	X		X	X	X			
4	Problem-solving skills and decision-making under pressure				X		X			X	X					X	X	X						
5	Skills in addressing environmental and sustainability issues in maritime logistics	X	X	X	X			X		X	X	X	X	X	X	X			X	X	X	X		X
6	Ability to understand the needs and requirements of clients and partners		X	X				X	X			X		X	X		X			X				X
7	Skills in networking and developing professional relationships		X	X		X	X	X	X			X	X	X	X	X	X		X	X			X	X
8	Ability to lead change and innovation processes in the port sector			X							X	X		X	X		X			X				
9	Experience in dealing with cultural and linguistic issues in a global business environment			X		X			X			X		X			X		X	X				
10	Ability to motivate and engage teams in pursuing common goals		X	X			X					X	X											
11	Experience in leading organizational change processes in port terminals				X		X		X			X					X	X					X	X
12	Time management skills and task prioritization in dynamic environments			X		X	X	X	X		X	X	X				X	X						X
13	Ability to communicate fluently in different languages in an international context		X	X		X			X			X	X	X			X				X		X	X
14	Experience in negotiation and conflict resolution in international business			X	X	X	X	X	X		X	X		X			X	X	X	X		X	X	X
15	Ability to lead corporate social responsibility projects in the port sector	X			X		X			X			X	X			X	X		X				
16	Experience in addressing health and safety issues in port environments portuários				X			X		X	X			X			X	X				X		
17	Specific Legal and Regulatory Aspects	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
18	Ethics and Social Responsibility	X		X						X	X		X								X			
19	Soft Skills in Maritime and Port Logistics				X	X			X		X	X					X	X			X		X	X
20	Remote Work and Crisis Management									X														
21	Leadership in Sustainability	X	X	X	X					X	X	X	X											
22	Networking and Collaboration in Renewable Energies		X	X				X		X	X	X										X		

C1 The University of Sydney
C2 University of Antwerp F. of Business Economics
C3 Copenhagen Business School - CBS
C4 Universidad del Pacifico E. de Negocios Ecuador
C5 KEDGE Business School
C6 Athens University of Economics and Business
C7 Alba G. B. School at the A. College of Greece
C8 The Hong Kong Polytechnic University
C9 University College Cork
C10 Kobe University - G. School of Business Adm.
C11 Erasmus University Rotterdam
C12 The University of Auckland
C13 Nova School of Law / Nova SBE
C14 ISEG Executive Education
C15 Escola Superior Náutica Infante D. Henrique
C16 Nova School of Science and Technology
C17 Instituto Politécnico de Viana do Castelo
C18 Nanyang Technological University (NTU)
C19 National University of Singapore
C20 Faculty of Maritime Studies of Ljubljana
C21 City University of London, C.S.E.
C22 Cardiff University
C23 Texas A&M University

Appendix B

Table B1. Mapping competencies in training programs.

Profile	Sector
Academic/Trainer/Consultant/Manager	Global Logistics
Technology Administrator for Services	Maritime and Port
Digital Innovation	Maritime and Port
Corporate Director	Maritime and Port
Development and Expansion Director	Maritime
Institutional Affairs and Business & Program Manager Railway Business	Railway and Port Transport
Logistics Director	Maritime and Port
Logistics Sales & Process Improvement Manager	Global Logistics
Member of the Board	Maritime and Port
Operations & Transshipment	Maritime and Port
Policy & Corporate Engagement	Maritime and Port
Procurement Management & Business Development	Maritime and Port
Sales, Project Management & Planning Director	Offshore Wind Energy
Sector Lead &Technology	Maritime and Port
Senior Project Coordinator	Maritime and Port

Table B2. Competencies Matrix.

	Competency Matrix	Average Rating
Technical	Competencies in port operations and logistics management	4,4
	Expertise in cargo handling operations and maritime transport logistics	4,2
	Proficiency in planning and managing port terminals	4,2
	Knowledge of maritime and port regulations and legislation	4,2
	Proficiency in multimodal logistics operations (maritime, land, and air)	4,1
	Expertise in container operations and cargo handling technologies	4,0
	Digital Transformation	4,0
Management	Capability to make strategic decisions in supply chain optimization	4,5
	Data analysis and decision-making based on information	4,4
	Leadership and team management skills	4,3
	Ability to lead and manage cross-functional teams	4,1
	Project management in the field of maritime logistics	4,0
	Ability to innovate and implement technological solutions in maritime logistics	4,0
	Negotiation skills and management of strategic partnerships and commercial contracts	4,0
Interpersonal	Flexibility and adaptability to handle complex and constantly changing situations	4,7
	Ability to work in teams and collaborate with professionals from different areas	4,6
	Ability to understand the needs and demands of customers and partners	4,4
	Ability to solve problems and make decisions under pressure	4,3
	Ability to motivate and engage teams in pursuing common goals	4,3
	Ability to communicate fluently in different languages in an international context	4,3
	Ethics and Social Responsibility	4,3
	Experience in dealing with cultural and linguistic issues in a global business environment	4,1
	Soft Skills in Maritime and Port Logistics	4,1
	Effective communication skills with various stakeholders	4,1
	Experience in negotiation and conflict resolution in international business	4,0
	Skills in addressing environmental and sustainability issues in maritime logistics	4,0
	Skills in networking and developing professional relationships	4,0

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Open Innovation and Innovation Ecosystem in Maritime Port: Review and Research Agenda

Maria Sabino [1,*], Cláudio Pinto [2], Maria Cabrita [3], Marcela Castro [4], Ana Mendes [5] and Tiago Pinho [5]

[1] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; mr.sabino@campus.fct.unl.pt
[2] APS - Administração dos Portos de Sines e Algarve – Sines, Portugal; claudio.pinto@apsinesalgarve.pt
[3] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal; m.cabrita@fct.unl.pt
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Research Center in Business Sciences - Universidade Beira Interior (NECE), Escola Superior de Ciências Empresariais, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; marcela.castro@esce.ips.pt
[5] RESILIENCE – Center for Regional Resilience and Sustainability, School of Business Administration - Polytechnic Institute of Setubal - Setubal Campus, Portugal; ana.mendes@esce.ips.pt; tiago.pinho@esce.ips.pt
* Correspondence: mr.sabino@campus.fct.unl.pt

Abstract: The maritime port sector plays a pivotal role in global trade and logistics, serving as a critical hub for the movement of goods. In this context, innovation is essential for enhancing operational efficiency, security, and competitiveness. This paper provides an exploratory literature review on the integration of open innovation and innovation ecosystems within maritime ports. By analyzing 35 academic articles, the study identifies key trends, challenges, and opportunities in leveraging collaborative practices to foster sustainable development and technological advancements in port operations. The review identifies the main thematic areas: open innovation in maritime ports, collaborative innovation practices, port innovation ecosystems, value creation, business models and innovation management. Based on this analysis, the paper proposes a future research agenda that highlights critical areas requiring further investigation and suggests pathways for practical implementation. The findings aim to guide stakeholders in the maritime industry towards adopting effective innovation strategies that enhance resilience and adaptability in an increasingly dynamic and interconnected global trade environment.

Keywords: Open Innovation; Innovation Ecosystem; Value Creation; Collaboration, Maritime Ports.

1. Introduction

Maritime ports, vital to global trade and logistics, increasingly use innovation to improve operating efficiency, security, and competitiveness. The confluence of open innovation frameworks and innovation ecosystems in maritime infrastructure is examined for their revolutionary potential. We uncover collaborative innovation trends, strategic challenges, and opportunities that support sustainable growth and technical improvement in port operations by analysing 35 research papers.

Innovation ecosystem dynamics, collaborative frameworks, value creation methods, emerging business models, and maritime innovation governance are covered in our comprehensive review. We may offer an ambitious research agenda that identifies important topics for study and develops viable implementation paths using this basis. The findings will help maritime stakeholders establish strong innovation strategies to improve port resilience and adaptation in a changing global commerce environment.

1.1. Background of the maritime port sector

Technological advances, economic developments, and changing government systems have transformed the maritime port industry. This business sector's history, present trends, and current difficulties must be examined to understand it.

Ports have always been vital to global trade, allowing the transport of commodities and resources. Maritime ports began as ship loading and unloading stations. Complex systems that combine shipping firms, terminal operators, and logistics providers have evolved [1], [2]. Containerisation in the late 20th century transformed port operations, increasing efficiency and requiring more modern infrastructure to handle bigger vessels [3]. This transformation required reevaluating port governance and operational strategies, emphasising the need for maritime supply chain coordination [4].

Digitalisation and innovation have changed maritime ports in recent years. Many port authorities are focussing on smart ports, which use digital technology to improve efficiency [5], [6]. These improvements streamline procedures and reduce port environmental consequences [7]. The concept of value co-creation has become popular in modern port ecosystems, where numerous companies collaborate to optimise services and produce shared benefit [8], [9].

Despite these advances, maritime ports have several challenges. Increasing global supply chain complexity and environmental concerns require more sustainable strategies [10], [11]. The requirement for governance and operational innovation is another obstacle. To overcome these difficulties and build a resilient maritime environment, public and private actors must collaborate [12], [13].

In summary, the maritime port industry has a long history as a trade facilitator, is evolving due to digitalisation and innovation, and struggles to achieve sustainability and good governance. Technology, teamwork, and environmental responsibility will shape the sector's future as it adapts to global changes.

1.2. Open Innovation and Maritime Port Innovation Ecosystem

To improve competitiveness and sustainability, maritime ports are adopting open innovation and innovation ecosystems. Innovation ecosystems are networks of individuals, organisations, and regulations that enable collaborative innovation, whereas open innovation uses external ideas and technology alongside internal resources. This work discusses maritime port applications of these principles, including successful case studies, digitalisation, and collaborative issues.

Fincantieri, a prominent shipbuilding company, and the National Research Council of Italy collaborate on an open maritime innovation. Fincantieri increased its innovation capability by partnering with different research organizations and institutions, proving the potential of open innovation to boost maritime operations [14].

Innovation ecosystems are important in ports because shipping firms, terminal operators, and local governments must work together to promote innovation. A comparison of Rotterdam and Valencia shows that effective innovation ecosystems have strong stakeholder linkages that allow knowledge and resource sharing [15]. These ecosystems help ports adapt to market needs and technological advances, making them more competitive in the global maritime context.

Digitalization is vital to maritime port innovation ecosystems. Spain's Ports 4.0 initiative funds digital projects to improve port logistics and operations to foster open innovation [16]. Such digital transformation efforts are essential for ports to remain competitive and responsive to the evolving needs of the maritime industry.

The path to open innovation and healthy innovation ecosystems is not without obstacles. The maritime industry has governance, stakeholder alignment and different interest integration difficulties [17]. Organizations in the maritime business must collaborate while competing for market share [18].

Finally, maritime ports should integrate open innovation and innovation ecosystems to boost competitiveness and sustainability. Ports can innovate and adapt to the fast-changing maritime world by collaborating with stakeholders and using digital technology. However, governance and stakeholder alignment must be addressed to fully realize these notions in the maritime industry.

2. Materials and Methods

A Scopus-based comprehensive literature review identified maritime port open innovation and innovation ecosystem research. In titles, abstracts, and keywords, the search strategy integrated innovation-related phrases ("open innovation, "collaborative innovation, "innovation ecosystem, "co-creation, "cocreation") with domain-specific terms ("port, "seaport, "maritime"). We employed numerous criteria to achieve comprehensive yet focused results: 2001–2024, peer-reviewed English journal publications only. To focus on maritime sector applications, we omitted biochemistry, chemical engineering, nursing, materials science, arts, earth sciences, and agricultural publications. This structured literature recognition method captured essential academic contributions while minimising noise from other topics.

Initial systematic search yielded 39 journal articles. After a comprehensive assessment, four papers were removed because they did not match our study objectives, while meeting the initial search criteria. The remaining 35 publications shed light on maritime port innovation techniques in the final analysis.

This selection method guaranteed the review was based on relevant, high-quality academic research, offering a solid analysis basis.

3. Results

The bibliometric analysis examines maritime port innovation research trends, including open innovation frameworks and ecosystem dynamics. Contributors, research evolution, and major institutions driving the discipline are shown in this investigation. The findings show that port innovation strategies are combining sustainability and digital transformation. Network analysis of academic contributions reveals established research clusters and developing topics that shape maritime port innovation practices.

3.1. Bibliometric Analysis

Figure 1 shows academic interest in maritime port innovation ecosystems rising from 2015 to 2024. The field has grown steadily from one publication in 2015 to seven in 2024, peaking in 2020 (5 publications) and 2022 (6 publications). Despite a brief decrease in 2023, the general increasing trend and recent high in 2024 reflect increased acceptance of innovation's importance in maritime port growth and modernisation.

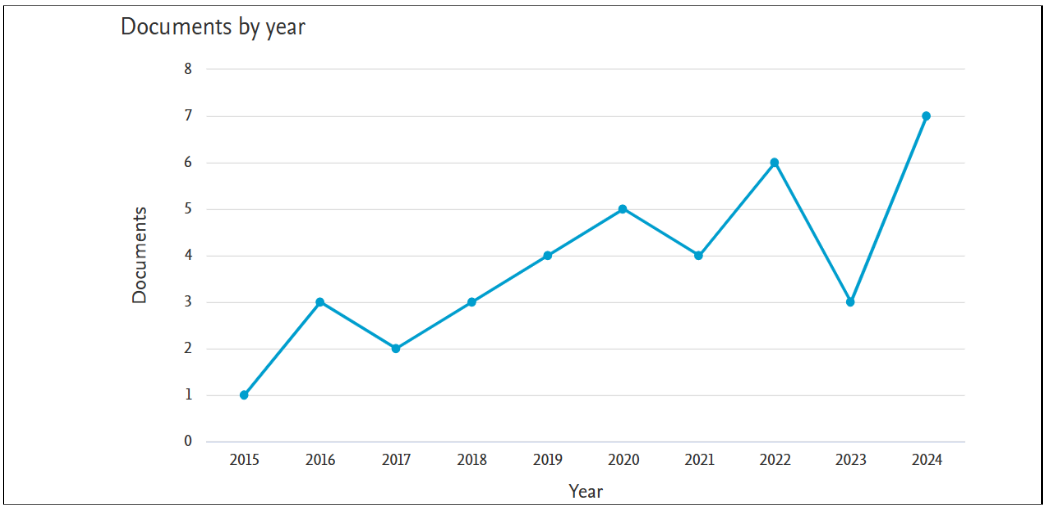

Figure 1. Analysis of publication trends from 2015 to 2024.
Source: Scopus database

Figure 2 illustrates a comparison of document production among various authors, concentrating on a maximum of 15 individuals. "Sys, C." is the most prolific contributor, followed closely by "Hermann, R.R." and "Vanelslander, T.", who demonstrate comparable publication output levels. The other authors, including "Acciaro, M." and "Brink, T., have produced a smaller number of documents. This visualisation clearly demonstrates the distribution of academic contributions among the specified researchers, revealing variations in the extent of their work in the field.

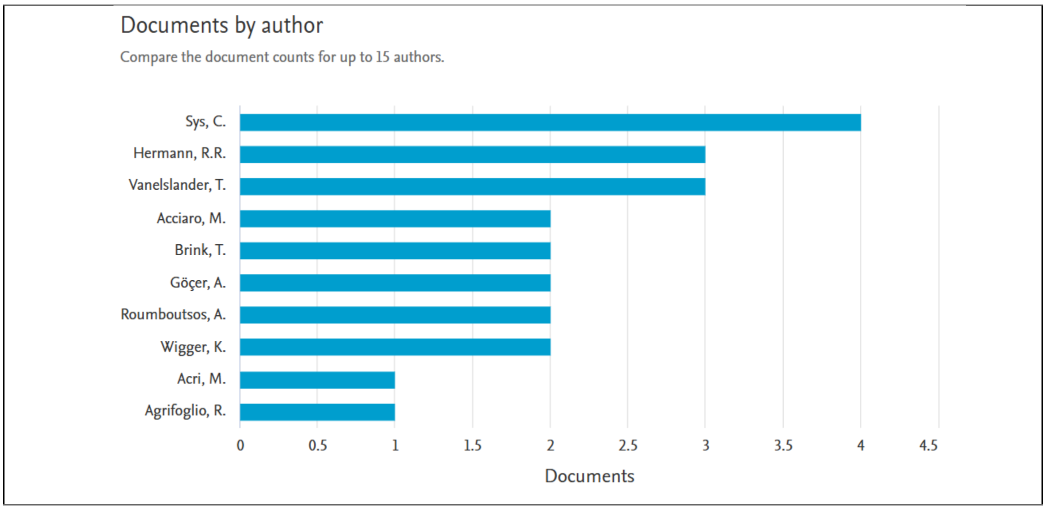

Figure 2. Documents by Author
Source: Scopus database

Figure 3 presents the distribution of documents categorised by country or territory, emphasising the research output from different nations. Denmark and Italy are the primary contributors, exhibiting the highest document counts, with the Netherlands following closely behind. Belgium, Germany, and Spain also represent significant contributors, each exhibiting a considerable degree of research activity. The chart indicates moderate contributions from Sweden, Finland, Greece, and Norway. This visual analysis highlights the geographic diversity in scholarly outputs, demonstrating the significant role of European countries in the relevant field of study.

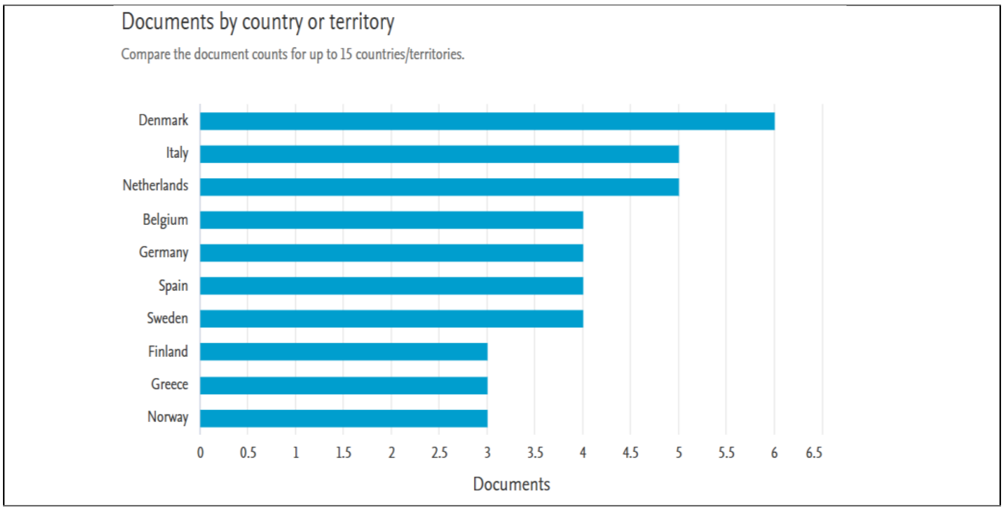

Figure 3. Documents by Country or Territory
Source: Scopus database

Figure 4 illustrates the document count categorised by academic affiliation, encompassing a comparison of up to 15 institutions. Universiteit Antwerpen ranks first in publication volume, followed by Aalborg University and Chalmers University of Technology, both of which exhibit considerable research productivity. Institutions like Instituto Superior Técnico and Delft University of Technology significantly enhance the document count. Subsequently, institutions such as the University of Southern Denmark, University of the Aegean, and Izmir Ekonomi Üniversitesi exhibit moderate levels of academic engagement. This figure illustrates the research contributions of various academic institutions, demonstrating the differing levels of engagement within the field.

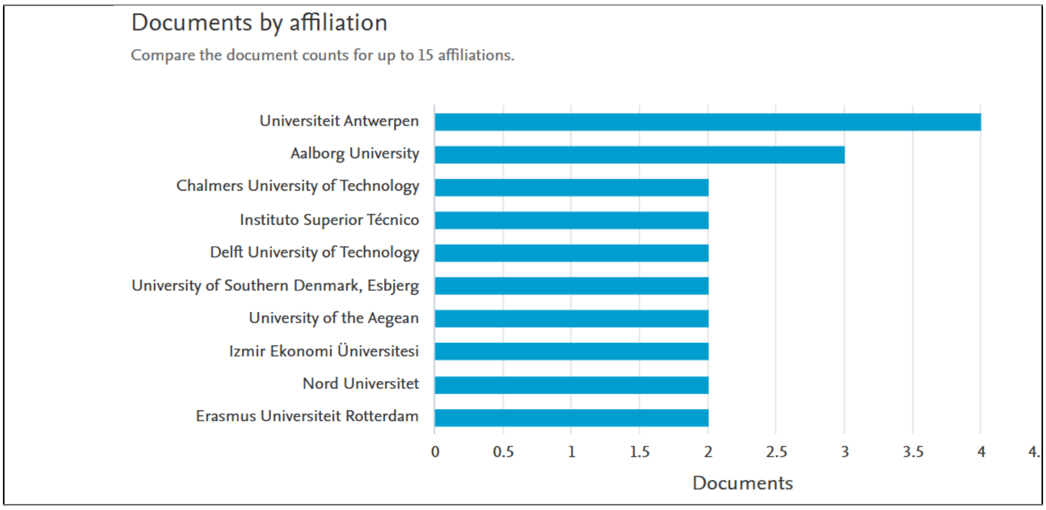

Figure 4. Documents by affiliation
Source: Scopus database

3.1.1. Co-authorship Analysis

Figure 5 illustrates a co-authorship analysis utilizing a full count and requiring a minimum of 10 citations per author. Among the 106 authors analyzed, 51 satisfy this criterion, demonstrating their considerable relevance in terms of citation within the literature on the topic.

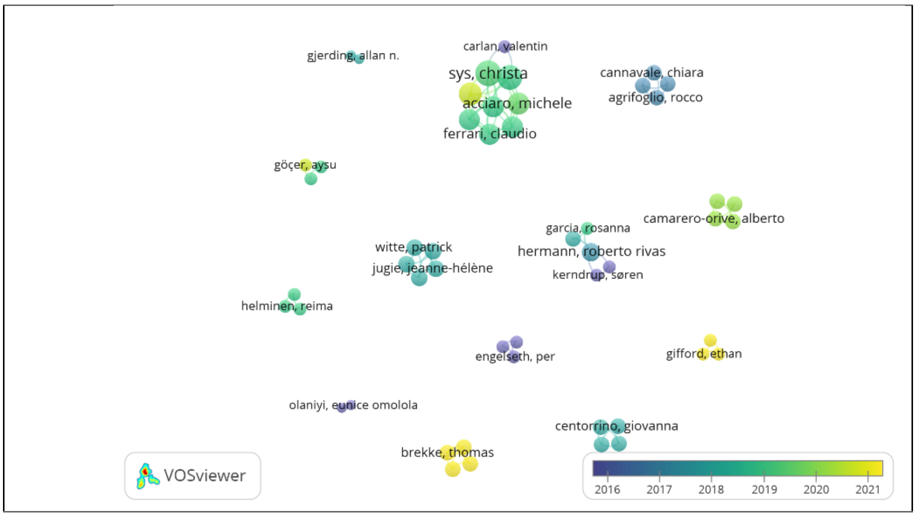

Figure 5. Co-authorship Analysis - Overlay Visualization

The closeness and quantity of connections among authors reflect the robustness of collaboration networks. Authors including Sys, Christa, Acciaro, Michele, and Ferrari, Claudio occupy central positions and exhibit numerous connections, indicating their prominence in the field and frequent collaborations with other researchers.

The color bar, extending from blue (2016) to yellow (2021), illustrates the temporal progression of publications. Recent collaborations among authors such as Brekke, Gifford, Göçer, and Roumboutsos, indicated by yellow nodes, highlight their significant contributions to emerging research.

3.1.2. Author Keyword Co-occurrence Analysis

A keyword co-occurrence analysis was conducted to obtain a deeper understanding of the thematic structure in literature concerning innovation in the maritime port ecosystem. This analysis employs author keywords as the analytical unit to identify key concepts and their interrelationships, thereby highlighting the most significant topics within the research field.

Figure 6 illustrates a co-occurrence network of author keywords obtained from a bibliometric analysis of 35 journal articles sourced from the Scopus database. The network was created using a full-counting method, establishing a minimum threshold of one occurrence per keyword. This approach yielded a total of 153 keywords, with 119 items constituting the largest interconnected set.

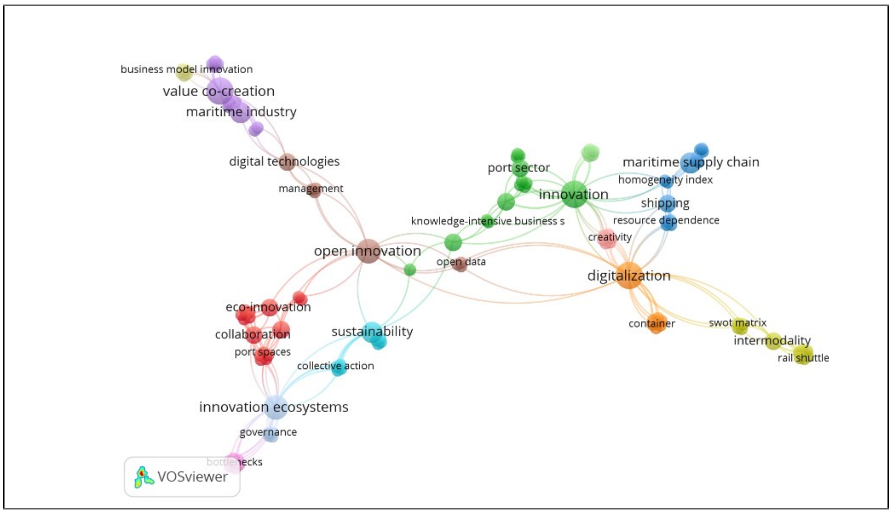

Figure 6. Author keyword Co-occurrence -Network Visualization

3.1.2.1. Analysis and Interpretation

This graphic shows how open innovation, innovation ecosystems, digitalization and marine supply chains are related. Closely linked nodes indicate significant thematic ties within each cluster. Open innovation is closely linked to eco-innovation, sustainability and cooperation, suggesting an emphasis on collaborative and ecological innovation processes in the port and maritime sector. However, governance and constraints are associated with the innovation ecosystem cluster, suggesting an emphasis on organizational and structural issues.

Note the absence of a direct link between open innovation and innovation ecosystem clusters. This gap offers research possibilities to incorporate open innovation approaches into innovation ecosystems, particularly in the maritime industry. This field can reveal how collaborative innovation affects ecosystem dynamics, governance frameworks and inter-organizational linkages in port operations.

This type of analysis is valuable for understanding research patterns and identifying potential gaps in the literature.

4. Conclusions

This research provides a preliminary review of the literature on integrating open innovation and innovation ecosystems within maritime ports. It emphasizes the critical role of these concepts in improving operational efficiency, security, and competitiveness in global trade.

The study highlights the key role of open innovation in enabling maritime ports to utilize external knowledge, engage in collaborative processes, and create value. Integrating open innovation practices can greatly improve competitiveness and resilience by fostering collaboration, adaptability, and sustainable growth. Involving various stakeholders, such as port authorities, shipping companies, technology providers, and academic institutions, is crucial for the successful implementation of open innovation. Knowledge exchange and engagement with stakeholders are essential for promoting innovation and value creation. While open innovation practices offer significant opportunities, they also pose challenges, such as infrastructure limitations and market characteristics. Addressing these challenges requires robust governance mechanisms, effective stakeholder engagement, and strategic open innovation management to fully exploit the potential of innovation in maritime ports.

Looking ahead, the research agenda suggests avenues for further exploration, highlighting essential areas for continued investigation and practical implementation.

This analysis serves as a foundation to guide maritime stakeholders towards implementing innovative strategies that bolster adaptability and resilience in the evolving global trade landscape.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53)

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Towards the integration of blockchain technology into eCMR management systems

Francisco Carreira [1,*], Paulo Rupino da Cunha [1], João Barata [1], and Jacinto Estima [1]

[1]University of Coimbra, CISUC, DEI; fmbc@dei.uc.pt; rupino@dei.uc.pt; barata@dei.uc.pt; estima@dei.uc.pt
*Correspondence: fmbc@dei.uc.pt

Abstract: In the fast-evolving landscape of logistics and transportation, the efficient and secure management of electronic consignment notes (eCMRs) is crucial. The eCMR standard, established by the United Nations Economic Commission for Europe (UNECE), provides a framework for the digital documentation of freight transport. While traditional eCMR systems often face security, transparency, and traceability challenges, Blockchain technology offers a promising solution to address them, by ensuring immutable, transparent, and secure data transactions. This paper shows how blockchain technology can be integrated into eCMR management systems in alignment with the UNECE standards. Following a Design Science Research methodology, we conducted a multivocal literature review and developed a proof-of-concept validated via a performance and cost evaluation. The impact of this research is significant for logistics companies, as the developed system aims to streamline operations by providing real-time visibility into the status and movement of consignments, enhancing data accuracy, and reducing the risk of fraud. Overall, the proposed system aims to enhance operational efficiency, security, and transparency for logistics enterprises.

Keywords: Blockchain technology; digital transformation; eCMR; transparency; security.

1. Introduction

The international carriage of goods by road is standardized by "The Convention on the Contract for the International Carriage of Goods by Road" (CMR), a United Nations convention signed in 1956 [1]. This convention ensures legal certainty and uniformity in the transport of goods across borders.

In 2008, the "Additional Protocol to the CMR Convention", introduced the electronic consignment note (eCMR), which allows for the replacement of traditional paper consignment notes, providing a legal framework for the digitalization of freight documentation [2]. However, despite these advancements, current platforms for freight documentation and logistics management often lack transparency, leading to inefficiencies and potential disputes.

Blockchain technology [3], fundamentally a distributed ledger system, allows data to be stored across a network of computers in a way that ensures security, transparency, and immutability. This technology presents a promising solutiono these issues by providing a decentralized, immutable ledger that can enhance transparency and traceability in the supply chain. Our work integrates blockchain with the existing eCMR framework to enhance the overall efficiency and transparency of freight documentation. It involves using blockchain to create a secure, tamper-proof system for recording and verifying consignment notes and other logistics-related data. Therefore, all parties involved in the supply chain can have real-time access to accurate and immutable information, significantly reducing the risk of errors, fraud, and dispute [4].

This paper is structured as follows: The **Material and methods** section details our Design Science Research (DSR) approach. The **Main results** section presents the produced artifacts, demonstrating how they behave in a real-world integration scenario. Finally, the **Conclusions** summarize the key points discussed, the implications for the logistics industry, and potential future developments in blockchain adoption.

2. Materials and Methods

The development of the eCMR management system adopted the Design Science Research (DSR) methodology, enabling the systematic creation and evaluation of innovative artifacts to solve identified organizational problems [5]. Firstly, requirement analysis was conducted using the standards available online from the UNECE [6] website and gray literature provided by UNECE and UN/CEFACT [7]. This information was used to build a high-level architecture and establish requirements for the system based on the individual needs of each actor involved in the eCMR process. We chose to utilize a public blockchain to leverage its transparency and security features, more specifically Amoy [8], an official testnet for Polygon [9], which ensured a robust and scalable platform for the development and testing of developed smart contracts. Given the requirements of the General Data Protection Regulation (GDPR) [10], it was required that only non-sensitive information was stored on the blockchain. To comply with the GDPR, sensitive data, namely XSD-compliant XML eCMR documents, are stored using Storj. Storj [11] is a decentralized cloud storage platform that ensures data security and privacy, allowing sensitive information to be stored off-chain while maintaining accessibility and integrity. To expose the functionalities of the system, we utilized Node.js and Express.js. These technologies allowed us to create an Application Programming Interface (API) that could handle HTTPS requests and interact with the developed smart contracts, thereby providing a secure and efficient means of accessing the blockchain functionalities through well-defined endpoints.

3. Results

The primary outcome of this project is the development of an eCMR management system leveraging blockchain technology and a decentralized storage solution, resulting in a robust and efficient tool for managing electronic consignment notes. Figure 1 presents a high-level architecture of the proposed system.

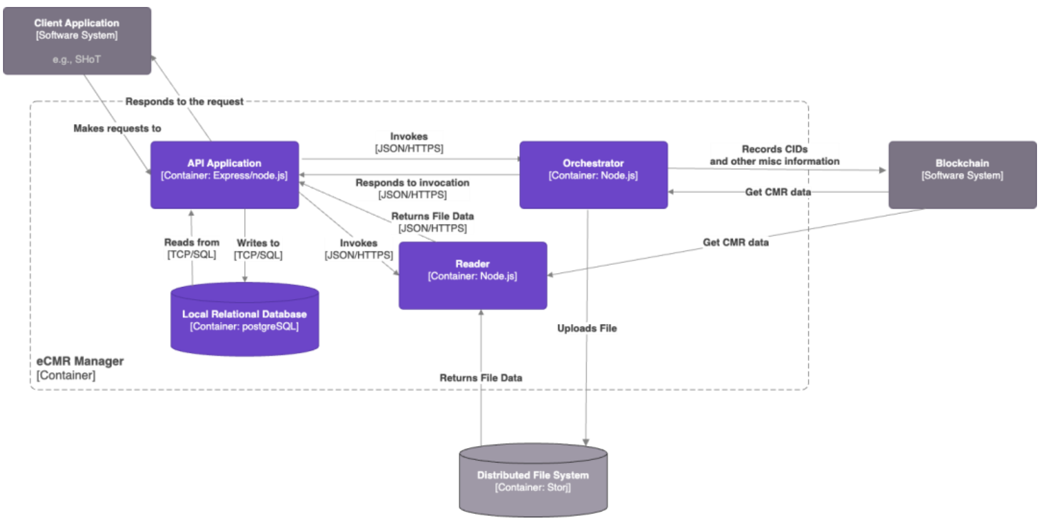

Figure 1. High-level architecture diagram.

Figure 1 showcases external systems, presented in gray, and the developed containers within the 70 eCMR Manager, which are highlighted inside the outlined area. As mentioned above, the API Application container exposes our solution via endpoints to any Client Application. Before submission to the smart contract and subsequent blockchain submission, operations are temporarily stored in the Local Relational Database. This database also serves as a cache to speed up document queries. Two core components were also developed: the Orchestrator and the Reader. The Orchestrator handles all the writing operations, whereas the Reader handles all the retrieval operations, including the retrieval of file pointers from the blockchain and the retrieval of the file from Storj according to that pointer.

Regarding on-chain storage, smart contracts on the blockchain allow for the storage and maintenance of records. At the heart of the system are two interdependent smart contracts: *CompanyManagement* and *DocumentStorage*. The *CompanyManagement* contract manages users and companies on the platform, ensuring only authorized entities can perform operations, thus maintaining the platform's integrity and security. Conversely, the *DocumentStorage* contract oversees the storage of all document records, accurately tracking signatures, versions, and audit requests to provide a comprehensive history and ensure data immutability and transparency.

The *CompanyManagement* contract utilizes the following structures: *Employee*, defined by a unique identifier, a public address, and a restriction level; *Company*, defined by a unique identifier, an array of company administrators, and a restriction level. The *DocumentStorage* contract contains structures for *Document*, featuring arrays of *Versions*, *Signatures*, and audit *Requests*; *Versions*, defined by a file content identifier (CID) and serving as a pointer to file location present in the decentralized file storage system, signer, and timestamp; *Signatures*, each defined by a signer and a timestamp; and *Requests*, also each being defined by a signer and timestamp.

Acknowledging the challenge for non-tech-savvy users to navigate cryptocurrency purchases, external wallet interfaces (i.e., MetaMask), or adapt from existing legacy systems, the interaction model with the blockchain was designed with such concerns in mind. Meta-transactions were implemented alongside a custom transaction signing mechanism via a popup. This allows users to engage with the blockchain without managing cryptocurrency directly, simplifying the experience by having a relayer (e.g., a wallet present in our system) submit transactions on their behalf. Furthermore, the custom transaction signing mechanism, operated through a popup interface, provides a straightforward way for users to sign transactions without in-depth blockchain knowledge. To ensure the security and authenticity of the transactions, we employed ECDSA (Elliptic Curve Digital Signature Algorithm) [12] and EIP-712 [13] standards for authentication methods and signed messages, available as external libraries from the OpenZeppelin framework. ECDSA provides a robust cryptographic technique to verify the authenticity of the transactions, while EIP-712 enables structured data hashing and signing, ensuring the integrity and non-repudiation of the signed data.

Lastly, to interact with the API and the smart contracts, a JWT (JSON Web Token) must be present and submitted via the Authentication header. This token, while encrypted, contains the employee's wallet address and the company unique identifier to which the employee is associated, serving as an Attribute-based Access Control (ABAC) schema, ensuring secure and authorized access to the system functionalities. The JWT is generated by signing a nonce (a number only used once) with the employee's private key and submitting the signed message to the system. Upon receipt, the system, using the ECDSA library, extracts the public key and retrieves the employee information from the *CompanyManagement* contract, thereby verifying that the user possesses the private key without ever submitting it to the system.

To evaluate the usability of the developed system, we conducted performance tests simulating real users making requests through a client application, using Postman as the API client platform to execute these requests. Each test was conducted multiple times, with write operations executed 10 times and read operations executed 20 times. Furthermore, all operations were submitted to the blockchain with a static gas fee of 30 *gwei*, the standard gas price for the Polygon mainnet, ensuring that all transactions have the same priority. Figure 2 exhibits the document-related write requests results.

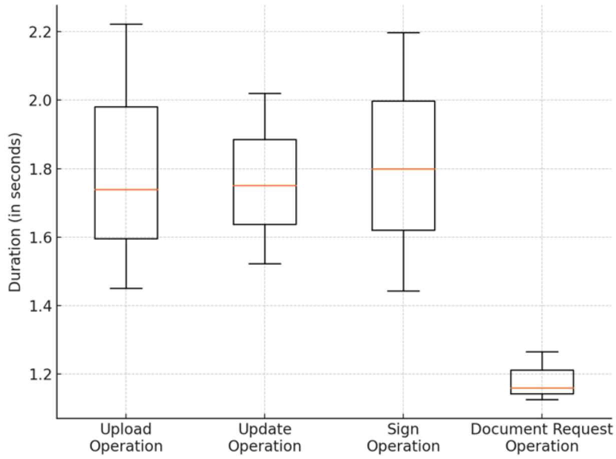

Figure 2. Duration of document-related write requests.

These requests involve more complex functions, as they interact with the decentralized file storage system, excluding the document request operation. The duration of the first three operations compromises the time needed for file upload and blockchain inscription. Lastly, the document request operation comprises the time needed for blockchain inscription and the creation of a temporary token for external viewership of a singular document. All operations' average duration stays below the two-second threshold.

Figure 3 shows the test results regarding read requests.

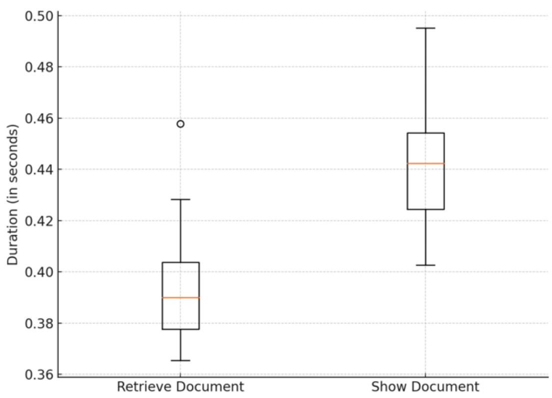

Figure 3. Duration of read requests to retrieve/show a document.

Our system applies file retrieval in two different operations: "Retrieve CMR" and "Show CMR". The difference between both operations lies in the rendering functionality. On the "Retrieve CMR" operation, no transformation is done, and the document is returned in the original XML format. Conversely, on the "Show CMR" operation, the retrieved file is transformed to PDF using XSLT. The average duration for both requests' ranges between 0.4 and 0.5 seconds, providing quick acknowledgement of the operation's success.

Overall, our system's average write operation duration is consistent and below the tolerable waiting time of approximately 2 seconds, as introduced in [14]. One aspect in which our system excels is the retrieval of information, with requests being addressed, on average, in under half a second. In conclusion, the performance metrics indicate that our system not only meets but exceeds the specified requirements for both write operations and information retrieval, which highlight the system's efficiency and reliability under normal conditions.

A usual concern with Blockchain-based systems is related with their operational costs. Table 1 presents a study of transaction costs in our system, replicating the gas price used above and assuming the price of the blockchain native token (MATIC) as 70 cents, a value 40% higher than at the time of writing (July 2024).

Table 1. Operation costs in gas (wei), MATIC, euros.

Operation	**Cost (in wei)**	**Cost (in MATIC)**	**Cost (in Euros)**
Associate Employee w/ Company	115,433	0.003463	0.002
Register Company	254,170	0.0076251	0.005
Register Employee	125,124	0.00375372	0.003
Restrict Company	29,258	0.0008777	<0.001
Restrict Employee	61,231	0.001843	0.001
Store Document	378,428	0.01135284	0.008
Update Document	201,119	0.00603357	0.004
Sign Document	241,878	0.00725634	0.005
External Audit Request	134,206	0.00402618	0.003

The table shows that the costs for all blockchain operations in our system are relatively low, ranging from below 0.001€ up to 0.008€. This indicates that the operations are economically feasible, even when considering multiple transactions. While the registration of employees and companies may signify a larger initial investment due to the number of employees and companies to register within the system, these expenses are still manageable within the broader context of operational costs. Furthermore, the low costs associated with document-related operations, such as storing, updating, and signing, highlight the cost-effectiveness of using blockchain technology for document management.

4. Conclusions

Our research demonstrates the feasibility and advantages of leveraging blockchain technology for eCMR management systems. Innovations such as meta-transactions and custom transaction signing mechanisms significantly enhance user accessibility, making the system suitable for non-tech-savvy users. Nonetheless, important limitations must be stated. Regulatory acceptance and standardization across different countries remain challenges that need to be addressed to fully realize the potential of blockchain in international logistics. Additionally, resistance to change and a lack of understanding of blockchain's benefits could obstruct its adoption. Despite these limitations, the benefits of blockchain integration in the international carriage of goods by road are substantial. By providing a secure, transparent, and immutable ledger, blockchain can greatly enhance the efficiency and reliability of freight documentation.

Future research should focus on fostering international collaboration to overcome the challenges of implementation and regulatory compliance. Finally, this paper aims to pave the way for more secure, efficient, and transparent eCMR processes, aligning with international standards and addressing existing challenges in the field.

Author Contributions: Conceptualization, F.C., P.R.d.C., J.B. and J.E.; methodology, F.C., P.R.d.C., J.B. and J.E.; software, F.C.; validation, P.R.d.C., J.B. and J.E.; formal analysis, P.R.d.C., J.B. and J.E.; investigation, F.C.; writing—original draft preparation, F.C.; writing—review and editing, F.C., P.R.d.C., J.B. and J.E.; visualization, F.C.; supervision, P.R.d.C., J.B. and J.E.; project administration, P.R.d.C., J.B. and J.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Project "Agenda Mobilizadora Sines Nexus". ref. No. 7113, supported by the Recovery and Resilience Plan (PRR) and by the European Funds Next Generation EU, following Notice No. 02/C05-i01/2022, Component 5 - Capitalization and Business Innovation - Mobilizing Agendas for Business Innovation. It was also funded through national funds by FCT - Fundação para a Ciência e a Tecnologia, I.P., in the framework of the Project UIDB/00326/2020 and UIDP/00326/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Evaluating Logistics Data for Machine Learning Applicability: A Decision Support Tool for Non-Experts

Vasco Costa[1,*], Diogo Costa[2,4], Ângela Brochado[3,4], and Eugénio M. Rocha[1,4]

[1] Department of Mathematics, University of Aveiro, Portugal
[2] Department of Mechanical Engineering, University of Aveiro, Portugal
[3] Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Portugal
[4] Center for Research & Development in Mathematics and Applications (CIDMA), University of Aveiro, Portugal
* Correspondence: vascovc@ua.pt

Abstract: With global supply chains relying heavily on maritime transportation, the evolution of ports is essential to manage increasing volumes and competitiveness. Modern logistics platforms should integrate Logistics 4.0 methodologies such as IoT, blockchain, artificial intelligence, cybersecurity, and digital partnerships, giving rise to the concept of smart ports, promoting more efficient and environmentally friendly operations. By nature, those operations generate a considerable amount of complex data, which makes it difficult for top managers to identify relevant case studies for Machine Learning (ML) applicability. To mitigate these issues, the LEDAT tool is proposed as a decision support tool for non-experts, which receives as input a logistic tabular dataset plus some related metadata and returns a graphical report with an extensive exploratory data analysis and ML estimations, e.g., estimating the effectiveness for predicting the value of specific variable. Using a profile-based execution mechanism, LEDAT guides users in their analysis through an automatic ML profile selection by using not only Conformal Prediction, a paradigm that provides statistical certainty, but also using a Large Language Model to support metadata enhancements. This tool provides top managers with a clear data viability report, aiding their decisions on investing in new ML solutions.

Keywords: Logistics 4.0; maritime ports; machine learning; exploratory data analysis; conformal prediction; large language models; big data.

1. Introduction

In today's world, approximately 90% of global trade is conducted via maritime routes, positioning ports as pivotal nodes within the global supply chain. This has intensified competition between ports and brought environmental concerns to the forefront of port operations [1, 2]. The rapid technological advancements of the Fourth Industrial Revolution, extending to the so-called Logistic 4.0, have compelled maritime ports to transform their operational procedures to accommodate increased throughput demands, leading to the emergence of intelligent port systems [3]. Intelligent port systems, or smart ports, although not having a clear definition in their current state have evolved significantly and are now in their fifth generation, incorporating Big Data, the Internet of Things (IoT), and Artificial Intelligence (AI) to optimize logistical operations from the supply chain to port activities [1, 2, 4].

The rise of smart ports is closely linked to the development of "smart cities" which integrate communication and information technologies to enhance various systems and improve the quality of life for individuals [5]. In particular, the resolution of some of these logistical challenges has enabled the development of solutions in densely populated urban areas for the transportation of goods and people in a more environmentally friendly and efficient manner [6]. Furthermore, the implementation of these technologies has the potential to enhance the sustainability and efficiency of existing urban rail transit systems, which collectively account for a relevant proportion of global freight and motorized passenger movements [7].

Handling the vast amounts of data generated by these systems is a significant challenge. Traditional tools are often inadequate for real-time responses, leading to the adoption of Big Data analytics. This approach has transformed many organizations, particularly in supply chain management, by enabling more efficient data processing and decision-making [8], a requirement in the contemporary age where data-driven solutions are the go-to approach [7]. For the case of smart ports, Big Data analytics is cited as a key success factor [9]. To function effectively, smart ports require the digitization of logistics and subsequent creation of dedicated platforms to collect, display, and distribute transportation requests where shared network approaches can be more advantageous than centralized ones [5]. The flow of data between physical and digital entities facilitates the creation of Digital Twins (DT), a synchronous copy of a physical entity to attain a virtual representation of it, which can combine Machine Learning (ML) [10]. This approach has already demonstrated considerable efficacy in forecasting truck arrival patterns, which has in turn led to a reduction in waiting times [4]. However, digital transformations of this magnitude necessitate substantial organizational changes, including investments in IT solutions, restructuring of internal activities, and the retraining of specialists [5]. As a whole, the integrational difficulties of Big Data in logistics have been a topic of much discussion [11]. To meet these challenges, it is necessary to develop innovative solutions that facilitate data analysis to enable the congestion of supply chains to be managed more effectively, further optimize port operations, and expedite the decarbonization of the industry. In comparison to other logistics, maritime logistics presents longer chains with a greater number of links and participants, which increases the uncertainty inherent to maritime logistics [10].

In other areas, the utilization of Exploratory Data Analysis (EDA) has been demonstrated to be beneficial, as it is a heuristic search technique that facilitates the discovery of significant relationships between variables. As it is heavily based on graphical techniques, these methods became popularized with non-data scientists. As the most prevalent initial methodology for data management, it plays a relevant role in the monitoring and estimation of Key Performance Indicators (KPIs) [6, 7].

Automatic ways to conduct this process already exist with different levels of users in mind. Many of these tools base their recommendation on either the data and a measure of a relevant subset of it or are log-based, using previous sessions to suggest the next step, with hybrid systems using both [12]. The identification of data subsets has been proposed with dataset meta-features, ranging from simple statistics to attributes of simple trained ML models [13]. This adds computational complexity, and the measure of *interestingness* is subjective and dynamically changes. In the case of log-based systems, the use of past trials can also be misguiding due to different users' interests. Moreover, conducting the registers needs to be done by experts and is challenging and extensive with the need to capture shifts through time. Moreover, benchmarking these systems is unattainable due to the different goals of users [12, 14].

As ML methods become more crucial in real-world applications, quantifying prediction certainty is vital. Many ML methods are judged by their overall performance, which shows large-scale impact but not individual prediction confidence. Predictions depend heavily on training data and the feature space topology, leading to higher confidence in well-represented, smooth areas versus complex, turbulent regions. Conformal Prediction (CP) tackles this by measuring prediction certainty based on the input's similarity to the training data, creating statistically valid prediction regions on top of point predictor ML algorithms [15].

The contribution of this work is thus the introduction of a tool for decision-making and automating data analysis procedures by providing end users, regardless of their experience in data science problems, with a guided route for which they can conduct data experiments and simple recommendations about ML data viability. Moreover, this tool is further proposed as a foundational component in providing initial Big Data analytics capabilities in the development of a Multimodal Control Tower (MCT).

2. Material and Methods

One of the key innovations promoted by the NEXUS Agenda is the development of AI-based applications for incorporation into an MCT. One of the requirements of this MCT is, naturally, the ability to automatically generate reports derived from input Big Data information flows, e.g., from the Janela Única Logística (JUL) platform and/or NEXUS' data APIs. However, the mere creation of programmatic reporting is of scarce value as this little contributes to retrieving high-significance insights from data. Rather, such a tool should be able to prepare data for subsequent injection into ML algorithms, whilst adequately evaluating which are the most relevant factors and providing non-data scientists with a guided path for solution developments. This paradigm resulted in the development of the LEDAT (*Logistics EDA Tool*). This modular analysis component can be integrated into existing digital twining platforms in a plug-and-play manner, including MCT systems. It contemplates the automated performance of many tasks typically associated with ML pipelines, such as the preliminary exploratory analysis of data, dataset preparation, or the complete application of ML techniques within business use cases.

Interfacing with the LEDAT is possible through a Graphical User Interface (GUI) and the first step is the dataset selection from the logistic data warehouse (e.g., NEXUS' data API). Then, the profiling selector component determines the set of adequate profiles to apply to the data. Each profile presents a series of EDA operations specially designed for logistics operations. The use of profiles is preferable as it takes on the role of tool selection and provides a guided path for analyzing without having to depend on the retraining of experts [5]. This also ensures that common pitfalls, such as that of not making proper use of the entirety information hidden on the data, so unsustained conclusions are avoided [16].

Among the input requirements, a dataset description is needed but can be the most difficult for the user, particularly since it is often that multiple analysis routes can be correct, depending on each problem formulation. For this, the GUI employs a text enhancer based on Large Language Models (LLM) with which users can textually interact with. These LLMs are then used to complement short descriptions and insufficient metadata of the dataset while allowing for a bi-directional interaction between the system and the user. With the inputs defined, the EDA operations are performed, based on the selected appropriate profile, and outputs are generated, such as analytics, graphics, and reporting information on the dataset. The results are served through an API to the HTML repository and directly through the GUI.

The complete architecture of LEDAT, including the aforementioned steps, is shown in Figure 1. The core element underlying the LEDAT tool is the so-called **Profiling Selector Component**. The primary responsibility of this component is the selection of valid analysis profiles given user input. For this, it is required the development of an ML model capable of predicting the most appropriate profile(s). In the initial stage, the conceptual implementation of this system was developed by using the openly available metadata from repositories UCI and Kaggle, from where relevant keywords were identified and agglomerated into the creation of a training dataset with multiple point predictors. In a production setting, this prototype implementation should be enriched with metadata belonging to specific logistics needs, or even particular enterprises (for in-house use).

However, classical point predictors limit the possibilities by only allowing for a single right answer and provide no statistical guarantee in the recommendation. Conformal Prediction (CP) addresses this by quantifying the certainty of predictions based on the similarity of the input with the training data, working on top of the point predictor ML algorithm, producing statistically valid prediction regions [15]. This inclusion allowed for the improvement of the predictors which minimized the error and accepted the possibility of having more than one correct profile which is fair since one dataset can have multiple study interpretations. Furthermore, this approach reduced the need for more complex models with greater computational resources.

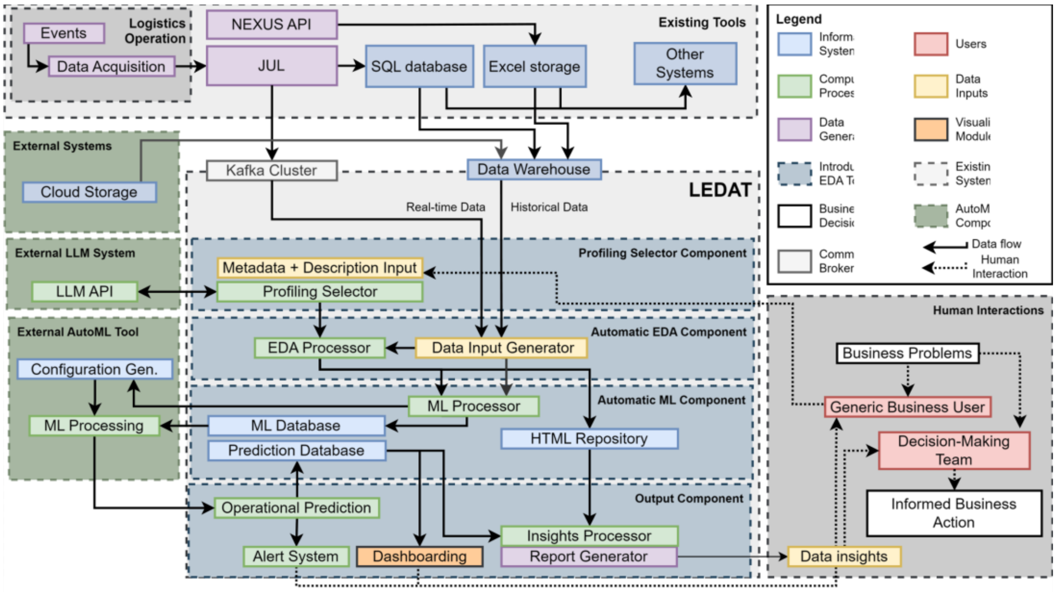

Figure 1. Schematics of the internal operations of LEDAT and its integration into existing logistic systems such as the MCT and digital twinning platforms.

To show the relevance and real application of LEDAT, a dataset describing loading/transportation operations on several terminals in the Port of Sines was used. The data ranges from Oct/2020 to Feb/2024 and has 1172 rows for terminal "Terminal Multipurpose", 624 rows for "Terminal Petroquímico", 218 rows for "Terminal de Gás Natural", 6993 rows for "Terminal de Granéis Líquidos", and 7619 rows for "Terminal XXI". Although not directly present, other variables can be obtained from the original data, for example, by subtracting the end of operation timestamp and the beginning of operation timestamp, it is possible to obtain a process duration as the *Operation Time*. Figure 2 shows some screens of the component regarding the profile selection.

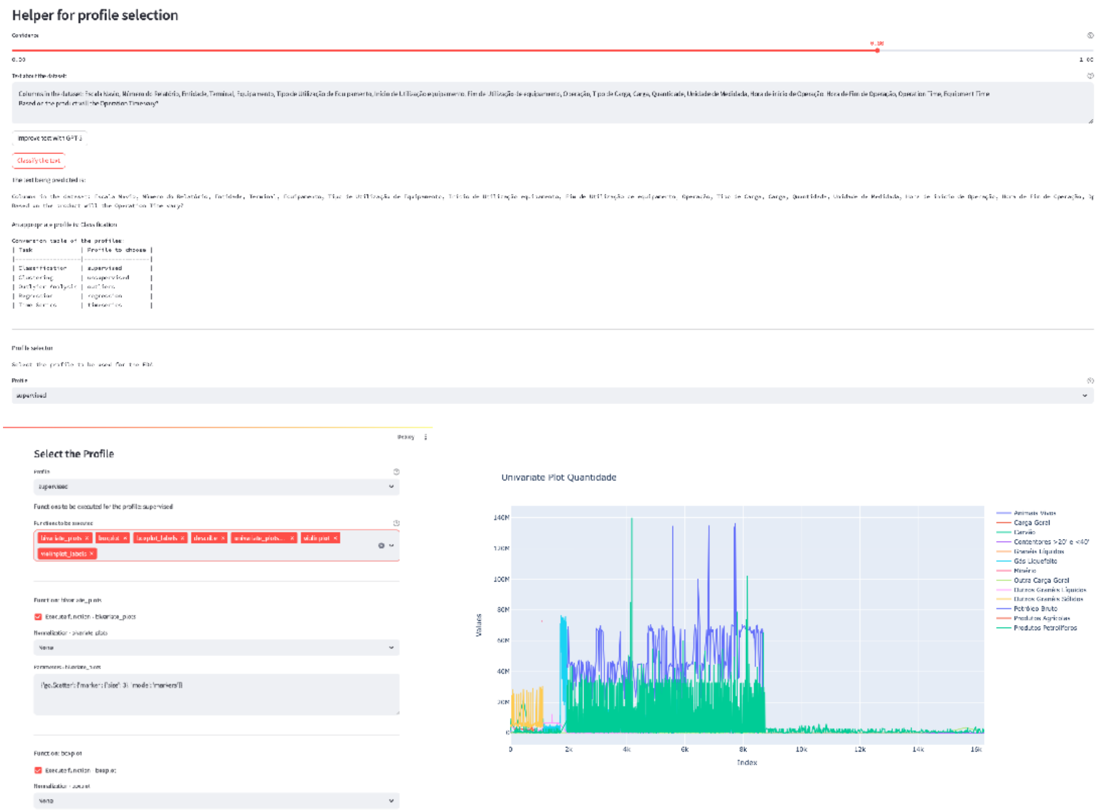

Figure 2. Screenshots of the profile selection steps on the LEDAT tool.

3. Main Results

For brevity of presentation and with the data uploaded to the LEDAT system, two scenarios can be discussed where the user is interested in studying different facets of the dataset. We assume that the columns present in the dataset are already integrated into the prompt of LEDAT.

- **Scenario 1**: The user wants to estimate/predict the operation time taken by an operation, so adding the text "I want to estimate the operation time based on the cargo type" and the system, by improving the text description with the LLM, will suggest the profile of *Regression* with target variable *operation time*.
- **Scenario 2**: Another possibility can be to perceive variations on the operation time according to the cargo type, and by adding to the prompt the text "Based on the cargo type will the operation time vary" the *Classification* and *Clustering* profiles are automatically suggested.

As can be seen from the above scenarios, it is possible to have different profiles for the same dataset, showing that more than one profile is suitable for ML applications.

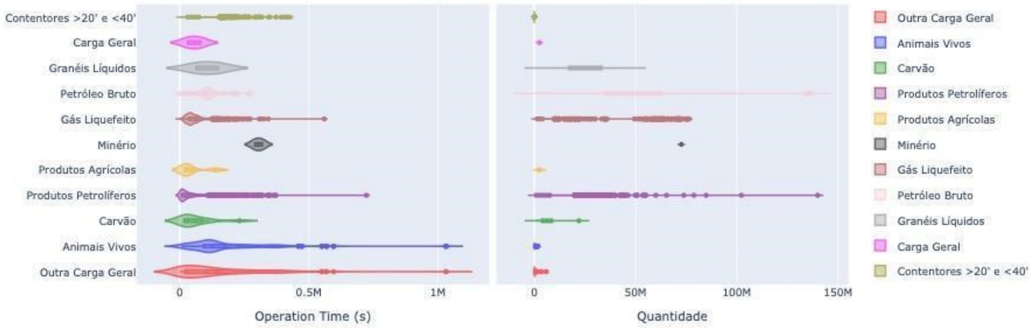

Figure 3. Two of the several graphs automatically generated after one profile was selected, as part of EDA component.

By considering the *Classification* profile and choosing the "Tipo de Carga" as the label target, it is possible to obtain multiple graphs associated with the Exploratory Data Analysis (EDA), where Figure 3 shows two of them. These violin plots of the operation time, and "Quantidade", i.e., the quantity of moved cargo, help to understand the relation between the data, their different volume and variability. Further other conclusions can be obtained from correlation heatmaps, scatter plots, pair-plots, histograms and many other interactive plots generated by the EDA component.

Concerning the presentation of the ML recommendations to users, a color system is used. For example, the *Classification* profile shows the (auto)ML estimated metrics in the colored system described in Figure 4. Two ML metrics were chosen: Accuracy and F-Score, where the last is especially relevant for imbalance classification problems. In this colored system, gray means inappropriate application of ML techniques, red means difficult data, yellow means careful considerations should be considered by data scientists, and green means adequate data for the *Classification* profile but overfitting may happen. This color system makes the comparison and choice decision between two datasets quite easy, since, in general, the one with a recommendation nearer to green/green will be the best one. Similar color systems exist for the other LEDAT profiles.

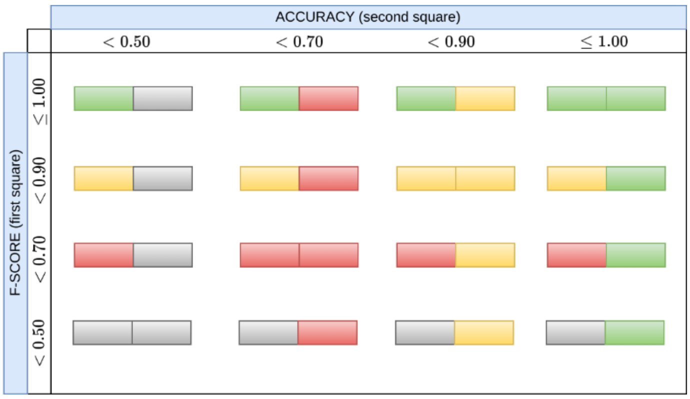

Figure 4. Colored recommendation system for ML metrics used in the *Classification* profile of a dataset, where each position represents a color-coded pair of values for both metrics.

4. Conclusions

Maritime ports have become indispensable components of the global supply chain, necessitating their transformation to accommodate increased volumes and maintain competitiveness. The process of analyzing data in this context thus presents both worthwhile contributions and significant challenges, as the extraction of valuable insights is often hindered by the sheer volume and complexity of the datasets involved, further hampered by the lack of data-savvy staff who can otherwise have extensive knowledge regarding the operational processes themselves.

The LEDAT addresses this challenge by enabling users with varying degrees of expertise to analyze data effectively, leveraging text inputs that can be enhanced by LLMs. Nevertheless, for LEDAT to achieve its full potential, adaptation to specific logistic data is required. These improvements will facilitate a more comprehensive and user-friendly experience, while simultaneously reducing the volume of output to prevent users from feeling overwhelmed with the many graphs produced by the EDA component. The incorporation of these advancements into the MCT's internal architecture will further enable its seamless extension to the logistics sector, as will be studied in future works.

Acknowledgments. The present work was developed within the scope of the "Agenda NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by PRR with no. C645112083-00000059 (investment project no. 53). The current work was inspired by a variant developed and tested in the manufacturing process in the scope of the "Agenda ILLIANCE" with no. C644919832-00000035 (project no. 46), also financed by PRR – Plano de Recuperação e Resiliência under the Next Generation EU from the European Union. The first and second authors hold grants in the scope of ILLIANCE. The third author has a grant in the scope of NEXUS. The last author was partially supported by the Center for Research and Development in Mathematics and Applications (CIDMA) through the Portuguese Foundation for Science and Technology (FCT - Fundação para a Ciência e a Tecnologia), references UIDB/04106/2020 and UIDP/04106/2020.

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POSTERS

Identifying and Categorizing Ports Decarbonization Barriers through the Sociotechnical Systems Theory

André Fadiga [1], Joana O. Andrade [1], João F. Bigotte [2] and Luís Miguel D. F. Ferreira [3,*]

[1] University of Coimbra, Department of Mechanical Engineering, Coimbra, Portugal; afadiga@uc.pt; jandrade@uc.pt
[2] University of Coimbra, CITTA - Research Centre for Territory, Transports and Environment, Department of Civil Engineering, Coimbra, Portugal; jbigotte@dec.uc.pt
[3] University of Coimbra, CEMMPRE, ARISE, Department of Mechanical Engineering, Coimbra, Portugal; luis.ferreira@dem.uc.pt
* Correspondence: luis.ferreira@dem.uc.pt (L.M.D.F. Ferreira)

Abstract: Climate change poses significant environmental, social, and economic challenges, necessitating urgent action from various sectors, including maritime ports. Despite their critical role in global logistics, maritime ports face numerous barriers to decarbonization, which complicates the implementation of effective strategies. This study addresses the gap in understanding these barriers by conducting a Systematic Literature Review, employing the PRISMA technique to select and analyze 33 relevant publications. Through this review, 25 significant barriers were identified and categorized using the Sociotechnical Systems theoretical lens, which includes social, technological, organizational, and environmental dimensions. The study reveals how the intricate interplay between these barriers contributes to a persistent reliance on fossil fuels, impeding progress toward decarbonization. The findings underscore the need for targeted mitigation strategies, suggesting that future research should validate these barriers through empirical methodologies like surveys and expert interviews. Additionally, future studies should focus on the interactions and interdependencies between barriers, utilizing methods such as Interpretive Structural Modeling to develop a more integrated approach to decarbonization. This research provides actionable insights to support the transition to sustainable maritime operations, ultimately contributing to global climate change mitigation efforts.

Keywords: maritime ports; decarbonization; barriers; sociotechnical systems; systematic literature review.

1. Background/Introduction

The impact of climate change, affecting environmental, social, and economic aspects, poses a potential global catastrophe. Despite this, business responses to climate change remain underexplored [1]. Decarbonization and net-zero commitments are becoming crucial for sustainable development. Particularly challenging sectors like shipping require multifaceted approaches for deep decarbonization. As essential nodes in global logistics, maritime ports are forced to combine practices, as relying on a singular "one-size-fits-all" approach may prove ineffective [2]. This complexity underscores the need for a comprehensive approach to decarbonization.

However, the adoption of decarbonization measures is influenced by numerous barriers, making it challenging for ports to plan and implement decarbonization strategies. The decarbonization of ports has already received some attention, and several studies have identified barriers related to the topic [3], [4], [5], [6], [7]. Existing studies usually focus on the barriers of specific measures, which is insufficient once there is no "silver bullet" for port decarbonization. Also, previous research has identified a need to explore port decarbonization barriers further [8]. To address the gap identified, this study was conducted to answer the following research question (RQ): What are the barriers to maritime port decarbonization? The findings of this study are crucial for understanding and addressing the challenges of decarbonization in maritime ports.

2. Material and methods

This study employs the Systematic Literature Review (SLR) method to identify and analyze relevant research on decarbonization barriers in maritime ports. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique was used to select the literature, design the data analysis, and ensure valid and reliable results [9]. The several steps of the application of the PRISMA technique are presented in *Figure 1*. The literature search was conducted using the *Scopus* database, which is considered to be the largest body of research in several fields [1], [10], [11]. The decision to use only *Scopus* is consistent with other studies in the operations and supply chain management fields, which found little added value in consulting additional scientific databases [12], [13], [14]. Each author conducted an individual eligibility analysis on the obtained articles, and the articles were selected or excluded based on consensus among all authors. This method allowed for the selection of 33 publications. A thorough examination of the barriers described in each article was undertaken. The identified barriers were categorized using the Sociotechnical Systems theoretical lens [15], [16].

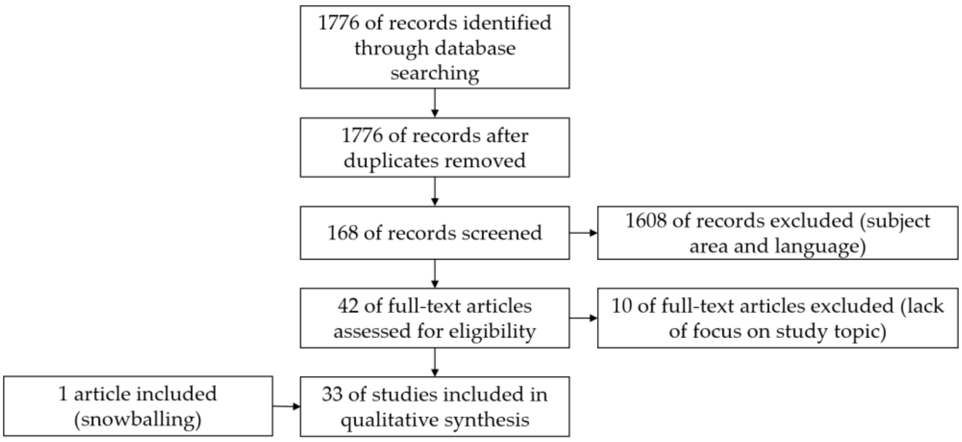

Figure 1. PRISMA flowchart.

3. Main results

Through the SLR methodology, 25 barriers were identified and categorized. Most articles do not comprehensively categorize the barriers, and those that do lack the application of any theoretical lens in their categorization. Due to the complex relationships between sociotechnical components and various actors in the maritime transportation sector, we believe the Sociotechnical Systems (STS) theoretical lens could provide valuable insights for researchers and practitioners seeking to develop strategies to overcome these barriers and promote sustainable maritime operations. STS are the synergistic union of people, technology, organizational structures, and the environment where all these dimensions coexist [17], [18].

The social dimension addresses the relationship between people and technology. The technology dimension focuses on technological aspects, such as complexity and interoperability with existing systems. The organization dimension explores characteristics like resources, processes, and structure. Finally, the environment dimension expands the analysis to assess the influence of external forces, including regulations and the market [19].

Through the SLR, 25 barriers to port decarbonization were identified, namely *High costs* (such as purchasing, capital, transaction, set up), *Low technology availability and readiness*, *Complexity of the industry*, and *Global policy gaps and instability*. Each barrier was defined and categorized according to the STS lens (*Table 1*).

Table 1. Port Decarbonization Barriers.

Category	Barrier	References
Social	Lack of awareness of environmental priorities	[1], [3], [4], [20], [21], [22], [23], [24], [25], [26], [27], [28]
	Limited knowledge, awareness, and expertise	[1], [3], [4], [22], [24], [27], [28], [29], [30], [31], [32]
	Resistance to change	[4], [21], [22], [24], [27], [28], [33], [34], [35]
	Lack of direct communication	[21], [23], [29]
Technology	High costs	[1], [3], [4], [21], [22], [25], [27], [28], [29], [32], [33], [35], [36], [37], [38], [39], [40], [41]
	Low technology availability and readiness	[1], [3], [4], [20], [21], [22], [24], [25], [26], [27], [28], [33], [39], [40], [41], [42], [43], [44]
	Lack of detailed and reliable data	[1], [4], [22], [23], [27], [28], [29], [32], [35], [36], [41], [45]
	Green fuel availability issues	[3], [20], [24], [29], [31], [33], [35], [38], [43], [46]
	Infrastructure retrofitting complexity	[3], [4], [22], [24], [25], [28], [30], [31], [40], [42]
	Standardization gaps in the integration of sustainable initiatives	[21], [23], [29], [34], [39]
	Long lifespan of ships	[36], [43]
Organization	Lack of coordination, collaboration, and cooperation (3C's)	[21], [23], [27], [29], [33], [34], [35], [36], [37], [38], [42], [46], [47], [48]
	Diminished visibility of the whole value chain	[3], [21], [24], [25], [29], [33], [37], [42], [43], [47]
	Absence of customized frameworks for decision support	[1], [4], [20], [25], [30], [32], [34], [37], [39], [49]
	Reluctance to invest	[1], [28], [29], [35], [37], [41]

Category	Barrier	References
	Reluctance to share data	[4], [23], [25], [29], [34], [41]
	Mismatch between present and future planning	[4], [22], [27], [30], [43]
	Conflicting goals in port systems	[1], [4], [35], [40]
	Hierarchical decision delays	[4], [32], [35]
Environment	Complexity of the Industry	[1], [3], [4], [20], [21], [22], [29], [30], [32], [34], [37], [38], [43], [45], [46], [48]
	Global policy gaps and instability	[1], [3], [4], [20], [25], [27], [28], [30], [31], [32], [34], [35], [36], [37], [38], [45]
	Uncertainties on policies, technologies, and next steps	[1], [4], [22], [29], [30], [32], [33], [35], [36], [37], [38], [43], [44]
	Lack of funding and incentives	[1], [3], [4], [22], [27], [28], [33], [35], [36], [37], [39], [40]
	Lack of government support	[1], [3], [4], [20], [25], [27], [28], [32], [35], [37], [48]
	Shipping Industry Growth	[26], [27], [28], [45]

Moreover, the study outlines mitigation strategies to address port decarbonization barriers, offering practical solutions that support policymakers and port authorities in effectively overcoming obstacles in the transition to sustainable port operations. Some mitigation strategies include creating *programs to reduce the cost and risk of launching technological innovation projects* and *fostering stakeholder collaboration.* The study highlights the interconnected nature of port decarbonization barriers and explains how efforts can fall short if only one barrier is addressed. This is due to the reliance of each barrier on others that remains unaddressed, underscoring the need for a multifaceted approach. Future research should focus on the interdependence of challenges in decarbonizing maritime ports to ensure sustainable operations in the maritime transport sector.

4. Conclusions

The study explores the barriers influencing the decarbonization of maritime ports, identifying 25 significant barriers through an SLR. By identifying, defining, and categorizing these barriers, the research explains how these constraints impact critical areas such as innovation, investment, and social responsibility within the maritime port sector. This study also reveals the intricate interplay between different types of barriers, which collectively contribute to a persistent reliance on fossil fuels and impede progress toward decarbonization. The categorization of the barriers through Sociotechnical Systems not only clarifies the specific nature of each barrier but also aids in developing targeted mitigation strategies. This approach enables stakeholders to devise more effective strategies for facilitating the transition to sustainable maritime operations, ultimately contributing to global efforts to reduce greenhouse gas emissions and combat climate change.

Several areas of investigation could significantly benefit future research efforts. Validating the proposed barriers is a critical next step, and empirical methodologies, like surveys and expert interview-based case studies, could be developed to do so. Moreover, with the help of the categories presented in this study, future research should focus on identifying targeted mitigation strategies for each type of barrier. As a result, future research can provide actionable insights and practical solutions to overcome the obstacles, facilitating a successful transition to low-carbon maritime port operations. Lastly, future research should investigate the interactions and interrelationships between these barriers, focusing on how they collectively impede decarbonization efforts. Methodologies such as Interpretive Structural Modeling (ISM) can be especially useful in determining how different barriers interact and identifying leverage points for intervention.

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Advanced Unmanned Aerial Vehicles Applications in Maritime Ports: Decision Making, Enhancing Inspection, Navigation, and Emergency Response

Gilvan Lima [1,*], Alexandre Santos [2], Ana de Jesus Mendes [3], Marcela Castro [4] and Tiago Pinho [3]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal; gilvan.lima@ips.pt
[2] GeoSense – Incubadora do Instituto Pedro Nunes – Coimbra – Portugal; alexandre.santos@geosense.info
[3] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; ana.mendes@esce.ips.pt; tiago.pinho@esce.ips.pt
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Research Center in Business Sciences - Universidade Beira Interior (NECE), Escola Superior de Ciências Empresariais, Campus do IPS – Setúbal, Portugal and; marcela.castro@esce.ips.pt
* Correspondence: gilvan.lima@ips.pt

Abstract: This study explores the advanced applications of Unmanned Aerial Vehicles (UAV) in maritime ports, focusing on decision-making processes, enhancing inspections, navigation, and emergency response. By using advanced imaging and sensing technologies, UAV streamline ship inspections, critical maritime missions planning and infrastructure assessments, boosting operational efficiency and resilience. Additionally, UAV aids in emergency response scenarios by providing real-time situational awareness to mitigate risks and minimize disruptions. UAV technology also contributes to environmental preservation by detecting oil spills and hazardous substances at sea. Integrating UAV with autonomous monitoring systems enhances safety, operational efficiency and cost-effectiveness in the maritime port industry. This study highlights ongoing projects and potential applications for UAV technology in various sectors. This research aims to promote continuous development and innovation in UAV technology and its application in ports worldwide, ultimately benefiting the maritime port industry and other related fields.

Keywords: Unnamed Aerial Vehicle; UAV; Maritime Port Industry; Ports; Technology Innovation; Technology Efficiency.

1. Introduction

The maritime port industry faces complex challenges in balancing operational efficiency, safety, and cost-effectiveness. Traditional methods of ship hull inspections, infrastructure assessments, and emergency responses often pose risks to human safety due to hazardous environments and operational complexities. Additional challenges include enhancing decision-making efficiency, operational efficiency, safety and security operation, and emergency response. In response to these challenges, UAV have emerged as a pivotal technology offering solutions to enhance operational capabilities while minimizing risks [1]. This study aims to analyze the advantages and potential of using UAV in the maritime port industry, investigating their impact on efficiency, effectiveness, safety, and cost reduction.

2. Materials and Methods

This study employs a detailed research approach, combining a documentary literature review and a detailed bibliometric analysis of the use of UAV for maritime port facilities. The literature review encompasses a wide range of sources exploring current trends and advancements in Unmanned Aerial Vehicle technology. The research had a specific focus on the practical implementations and benefits of UAV within the worldwide port industry.

3. Results

The perspective that the use of Unmanned Aerial Vehicles offers a potential solution to mitigate risks and reduce operational costs in such scenarios underscores the transformative potential of UAV in various aspects of maritime port operations. In the context of port efficiency, UAV equipped with advanced imaging and sensing technologies enable efficient and comprehensive ship hull inspections, reducing inspection time and increasing accuracy compared to traditional methods. Critical maritime mission planning using neural networks allows for rapid identification of target vessels, prioritization of vessels to be visited, and reduction of waypoints in the flight plan [1].

UAV can also estimate the distance between ships and obstacles in congested ports by using the global navigation satellite system (GNSS) and long-range aerial imagery. The combination of UAV technology with Visible Light Communication (VLC) technology effectively tracks maritime targets. Based on the UAV-VLC system, a geometric algorithm is proposed to obtain an approximate position, then the geometric algorithm is transformed into the Linear Iterative Positioning (LIP) algorithm and the Quadratic Approximation Iterative Positioning (QAIP) algorithm to reduce computational complexity and ensure solution uniqueness [2]. With all this information available in real time, the decision-making process has become more agile and much more precise in terms of mobilizing the appropriate resources and the right size to deal with each situation that arises.

Regarding infrastructure assessments, UAV enables rapid data collection and analysis, supporting proactive maintenance strategies that enhance the resilience and longevity of port infrastructures. Additionally, UAV plays a critical role in emergency response scenarios, providing real-time situational awareness, and enabling quick and coordinated actions to mitigate risks and minimize operational disruptions [1].

UAV are used for offshore energy plant inspections, marine life observation, and search and rescue missions, using onboard cameras to detect and locate landing platforms or objects at sea [3]. They also monitor breakwaters and other port structures, capturing high-resolution aerial images to generate point clouds and ortho mosaics, facilitating visual inspection processes and assessing structural condition [4].

In terms of traffic safety in port areas and their movement and congestion limitations, both at sea and on land, the application of UAV has been increasingly expanded. This aims to improve communication and capture positioning signals, providing system users with greater safety in their movements while representing efficiency in the port production chain. This enhances docking conditions and cargo movement, ensuring safe navigation within often congested port spaces and waterways [5]. In this same context of improving maritime traffic communication systems, UAV contributes to the integration into sixth-generation Maritime Communication Networks (MCN), emphasizing their role in extending connectivity and enhancing Internet of Things (IoT) applications in smart ports [6].

Although integrating UAV in sixth generation (6G) Maritime Communication Networks (MCN) topologies demonstrate a significant improvement in communication links and operational efficiency, it results in the formation of an aerial segment that complements shore base stations, which may offer insufficient coverage, and satellite communication, which is often characterized by increased delays. In this study, we focus on an MCN where direct links to shore base stations are unavailable due to excessive fading conditions. In such scenarios, we deploy a swarm of UAV to provide enhanced wireless connectivity, using non-orthogonal multiple access (NOMA) for high resource efficiency. This new modelling approach has been shown to improve signal speed and reduce average delays, thereby optimizing the overall communication network [4].

UAV technology can also contribute to environmental preservation. UAV equipped with sensors can detect and georeferenced oil spills and other hazardous substances at sea to aid in maritime situational awareness [7]. UAV and autonomous surface vehicles adapted to release microorganisms for bioremediation of oil spills offer a rapid and efficient response to pollution incidents in ports and industrial areas [8].

The integration of UAV with other autonomous monitoring systems represents a significant leap for the maritime port industry, offering substantial improvements in safety, operational efficiency, decision making and cost-effectiveness. The cooperative UAV-USV system, introduced as a technological innovation, is expanding operational coverage and optimizing resource utilization [1].

Table A1 (Appendix A) provides a clear and concise overview of the key advantages UAV offers across different operational domains, highlighting their transformative potential in enhancing management practices and illustration of the UAV usage, including bibliographic literature to support the search for information.

Also, in Figure A2 (Appendix B) there is an illustration of the various results and benefits of UAV applications. Each rectangle represents a specific benefit, with the size of the rectangle indicating the relative frequency or significance of that benefit. The chart visually summarizes the diverse advantages UAV technology brings across multiple domains

4. Conclusions

According to this study, we can see the immensity of new prospects for the application of UAV in the maritime port industry. Considering the extensive work that has already been done and the applications that have already been implemented, one could already have a significant impression of the new technology that is being used. However, there are also ongoing projects that address various existing and future application areas. These areas require much more study and technological advancement to be effectively applied in the highly demanding environment of the maritime port industry.

As such, we have had the opportunity to see the effects of using the UAV to make decision-making more efficient, both in day-to-day tasks and in critical emergency situations. It is also clear from the studies analyses that inspections of both ships and port structures have been able to achieve much more significant results in terms of identification quality and reduction of human exposure to the risks involved in such activities, which will certainly represent a significant reduction in costs for port operations.

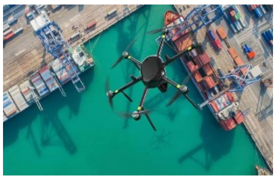
Nevertheless, environmental control and its mitigating and corrective actions are another area in which the progress in the implementation of UAV has proven to be extremely effective and tends to be more and more widespread given its contribution to reducing the impact caused by accidents, given the speed with which they can be identified, and the actions taken to combat and neutralize their effects.

All this data collected allow us to see that there is a very promising path for this technology to follow and that the maritime port industry itself is eager to follow this development since it has experienced the positive effects of this technology, which is growing every day in all the world's ports.

The main practical contribution of this manuscript lies in the identification and dissemination of the various applications of UAV technology. By making this knowledge explicit, the aim is to enable its application in different ports around the world, thus promoting the continuous development of this technology. In addition, this research opens avenues for exploring these applications in other areas, thus promoting continuous innovation and adaptation in different sectors.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53)

Appendix Table A1

Domain	Advantages of UAV	References	Illustrations
Maritime Traffic Management	Improved signal transmission, enhanced communication, and better management of maritime operations.	[9], [10], [11], [12], [13]	 Source: [14]
Environmental Monitoring and Pollution Control	Real-time environmental data, efficient pollutant detection, prompt response to pollution incidents, and accurate emissions data collection.	[15], [16], [17], [18]	 Source: [14]
Accidents and Disasters	Precise and timely data collection, faster deployment in emergencies, and improved decision-making during crises.	[3], [19], [20], [21]	 Source: [14]
Patriotic Security and Safety	Enhanced national security through accurate surveillance, improved traffic control in ports, and real-time monitoring.	[5], [7], [12], [22], [23]	 Source: [24]
Operational Efficiency	Cost-effective and efficient inspections of ships, port structures, and clean energy installations.	[1], [10], [25], [26], [27]	 Source: [14])

Appendix B Figure A2

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Resilience of information flow in port operations: a bibliometric analysis

Carlos Batista [1,*], Cláudio Pinto [2], Tiago Pinho [1] and Ana Barroso [3]

[1] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; carlos.batista@esce.ips.pt; tiago.pinho@esce.ips.pt
[2] APS – Administração dos Portos de Sines e do Algarve, Sines, Portugal, claudio.pinto@apsinesalgarve.pt
[3] Laboratório Associado de Sistemas Inteligentes (LASI) and UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Nova University of Lisbon, 2829-516 Caparica, Portugal; apb@fct.unl.pt
* Correspondence: carlos.batista@esce.ips.pt

Abstract: In the era of digital transformation, seaports can benefit from the incorporation of Industry 4.0 technologies in their Port Community Systems, contributing to making them more resilient and sustainable. This transformation requires higher levels of organizational integration, information integration, and technological innovation in the supply chain, as well as an increase in the resilience of the information systems. Although there are studies in other sectors, the resilience of Port Community Systems 4.0 in port environments is an emerging field with several literature gaps. The objective of this article is to identify areas of research, trends and gaps in the literature published in the Scopus and Web of Science (WOS) databases from 2012 to 2024. The VOSviewer, a software tool for building and visualizing bibliometric networks, is used to analyze co-authorship, co-occurrence of keywords, citations and bibliographic coupling. This study involves searching for articles on the Scopus and WOS platforms and using bibliometric analysis to visualize research themes, trends and gaps.

Keywords: Resilience; Seaport; Port Community System; Hinterland; Industry 4.0

1. Introduction

The disruptions in global supply chains have been a hot topic in recent years due to the impact they have on the normal operations of the organizations that constitute them and ultimately on the normal functioning of society [1][2][3]. Depending on the circumstances, a disruption may interrupt the normal flow of goods, generate risks involving financial losses and reputational damages for organizations before their stakeholders (e.g. customers, partners, government bodies, etc.) [4]. To deal with these events, organizations are undertaking efforts to become more resilient in a supply chain logic, of which they are constituent parts [5]. This reality has led to increased interest in methods and tools for dealing with disruptions, promoting increased resilience in supply chains.

The classic definition of "supply chain resilience" consists of the ability of a system after being disturbed to return to its original state or transition to a better state than the original. However, there are other proposals in the literature [6]. Supply chain and operations resilience is designed to prevent serious and unexpected disruptions and to restore operations afterwards [7]. For all actors involved in a supply chain, a greater degree of resilience allows them to anticipate and respond to threats and opportunities that arise from sudden or gradual changes in the environment where they carry out their activity, that is, to develop their ability to absorb and adapt to a changing environment [8].

The market for digital transformation solutions in the logistics sector gained significant momentum in 2021. With the advent of the Covid-19 pandemic, major adjustments were made to global supply chains and logistics networks, intensifying the need for more digital operations, i.e. more automated, more scalable and with less need for human interaction. This digital transformation has created growing interest in the value of digital technologies for end-to-end supply chain visibility and their potential use to increase resilience [9]. Organizations aim to rebuild supply chains based on data and informed by artificial intelligence, making them more resilient and providing efficiency with sustainability in mind [10]. The accelerated transition from traditional supply chains to omnichannel chains and international transportation, 80% of which is carried out by ship [11], are being challenged by macro-political and macro-economic aspects, namely geopolitical tensions and conflicts, and growth uncertainty, which create the need for more flexible and resilient logistics networks [12]. Another major trend to consider is the pressure on the logistics sector to become more sustainable, particularly in transportation (e.g. the MARPOL convention requires that as of January 2023, ships calculate their Energy Efficiency Index, so that they can improve their energy efficiency in the short term [13]), which currently accounts for a quarter of all greenhouse gas emissions. This is happening in a scenario where traffic is expected to increase by 60% by 2050 [14][15].

According to the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) team working in the field of Logistics, the fourth industrial revolution (Industry 4.0) is coming to maritime transport, including digitization, robotics, artificial intelligence and big data [16]. Seaports, as key entities in global supply chains where physical and informational flows are increasingly complex, are simultaneously facing a digital transformation and a green transition. The digital transformation itself represents a very powerful "engine" for the green transition, helping to tackle the relevant inefficiencies in the sector. Existing studies demonstrate the potential contributions of digital transformation, including the application of technologies such as AI, big data, IoT, social networks and mobile technologies, to the environmental, economic, and social sustainability aspects [17].

Modern organizations depend on information and communication systems and the collaborative relationships established in the supply chain to operate effectively and efficiently [18]. A Port Community System (PCS) is a neutral and open electronic platform that: (1) enables the intelligent and secure exchange of information between public and private stakeholders to enhance the competitive position of seaport communities; (2) optimizes, manages and automates port and logistics processes through a single data feed and connects to transport and logistics chains [19]. Considering the complexity of both the technologies involved and the relationships established in a Port Community System 4.0 (PCS 4.0) among different stakeholders, it is crucial to develop and implement collaborative resilience strategies in the supply chain. However, most PCS are still in an evolutionary phase, focusing on basic operations, and maintaining connection systems among the port's actors to facilitate shipping and cargo operations [20]. Some PCS have only recently started expanding into the hinterland, associated with the regionalization of ports, to include other players of the supply chain and create synergies with land transport nodes and other players in the logistics networks [21]. This involves collecting cargo location information using sensors and providing it transparently [22].

The ongoing digital transformation 4.0 underscores the importance of intensifying studies on the resilience of information flow, which plays an increasingly crucial role in the performance of port activities, especially considering specific regulatory requirements that apply to ports operating under various national and international jurisdictions. However, there is a lack of specific literature on how digital transformation (in an "Industry 4.0" context) can positively impact the resilience of information flows in seaports, which are critical nodes in global supply chains [23]. The development of a bibliometric analysis can foster future research by assessing the current state of academic productivity, identifying trends and gaps in research, and mapping collaboration networks between researchers and institutions in this knowledge area [24].

2. Materials and Methods

The methodology proposed for conducting the bibliometric analysis consists of four main stages as proposed by Donthu *et al.* [24]:

(I) Defining the objective and scope of the study;
(II) Choosing the techniques for bibliometric analysis;
(III) Collecting data for bibliometric analysis;
(IV) Carrying out the bibliometric analysis and reporting the results.

The first stage defines the scope of the study, which consists of studying the resilience of PCS 4.0 in a port environment.

The second stage consists of conducting a bibliometric analysis using VOSviewer software [25], employing the following bibliometric techniques: (1) co-authorship - to examine the social interactions or relationships among authors and their affiliations, and their impact on the development of the research field; (2) co-occurrence of keywords - to analyze the written content of the publication itself and explore existing or potential relationships between research topics; (3) citations – to assess interrelationships by identifying the most influential papers published within a specific field; and (4) bibliographic coupling - to examine relationships between cited publications and understand the historical or current development of research topics in the field.

In the third stage, data will be collected from the Scopus and WOS databases, covering the period 2012-2024 (2012 corresponds to the earliest date from which results are displayed in the databases for the simple search "Industry 4.0" in the "Title, Abstract and Keywords" fields). The search queries to be entered into the databases will use a combination of the following keywords: "disruption", "resilience", seaport", "port community system", hinterland", "industry 4.0" and "4.0", using logical operators such as "AND", "OR", "NOT" and "AND NOT". The search will be limited to documents in the English language and to the following document types: article, conference paper, and book chapter.

The fourth and final stage involves conducting a bibliometric analysis and presenting the results.

3. Main contributions and expected results

The development of bibliometric analysis can promote future research by assessing the current state of academic productivity, identifying trends and gaps in research, and mapping collaborative networks among researchers and institutions in the resilience of PCS 4.0 knowledge domain. With VOSviewer software, bibliometric networks can be visualized in detail using zoom and scroll features. Density visualizations provide a quick overview of the main areas within a bibliometric network, while overlap visualizations illustrate evolution over time. The results of the bibliometric analysis will allow the researcher to direct his efforts towards carrying out a systematic review of the literature on the resilience of PCS 4.0 in ports, assessing with rigor and depth the current state of academic productivity, and presenting the main scientific output in a synthesized manner.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project nº 53)

The fourth author acknowledge Fundação para a Ciência e a Tecnologia (FCT - MCTES) for its financial support via the project UIDB/00667/2020 and UIDP/00667/2020 (UNIDEMI).

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Logistics and Technology Projections for 2030: A Comprehensive Marine Port Report

Gilvan Lima [1]*, Bruno Rocha [1], Nuno Gonilho [1], Cláudio Pinto [2], Ana de Jesus Mendes [3], Marcela Castro [4] and Tiago Pinho [3]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal; gilvan.lima@ips.pt; bruno.rocha@esce.ips.pt; nuno.gonilho@estudantes.ips.pt
[2] APS - Administração dos Portos de Sines e Algarve – Sines, Portugal; claudio.pinto@apsinesalgarve.pt
[3] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; ana.mendes@esce.ips.pt; tiago.pinho@esce.ips.pt.
[4] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal and Research Center in Business Sciences (NECE); Universidade Beira Interior; marcela.castro@esce.ips.pt.
* Correspondence: gilvan.lima@ips.pt

Abstract: The study focuses on the future of the maritime port industry and the impact of technological advancements and regulations on marine port operations. This work is essential for guiding the maritime port industry towards a future of enhanced efficiency, security and sustainability through the strategic adoption and regulation of cutting-edge technologies. It highlights key emerging technologies discussing their benefits and potential applications in port logistics. The study also delves into regulatory and legal considerations, emphasizing the importance of compliance with international standards. By conducting a thorough analysis of emerging trends and technologies, the document aims to provide insights for industry practitioners and contribute to the modernization and efficiency of the maritime port sector. Through data research and in-depth exploration of current and future technologies, the document serves as a valuable resource for knowledge sharing and benchmarking in the maritime port industry.

Keywords: Maritime Port; Seaport; Technology; Digitalization; Trends; Regulations.

1. Introduction

The maritime port sector is vital to the global economy, facilitating international trade and large-scale movement of goods. With advancing technology and evolving regulations, understanding emerging trends is vital for the future of the port industry [1].

Digital technologies in port logistics are becoming globally important due to the need for policymakers, port authorities, and shipping companies to develop digitalized and sustainable processes. In a data-driven, globalized trade context, a data-based approach is essential for smart and sustainable logistics development [2].

Innovative technologies like Automated Guided Vehicles, Unmanned Aerial Vehicles, Virtual Reality, Digital Twins, IoT, AI, and Blockchain are increasingly used in port activities. These technologies, along with regulatory and legal considerations, are transforming port operations worldwide. This model employs IoT, sensors, cloud computing, Big Data Analytics, AI, GPS tracking, radars, drones, real-time monitoring, and smart grids to collect, process, and analyze data concerning economic, environmental, and technological aspects of port cities [2].

This study aims to provide a comprehensive overview of emerging technologies expected to be implemented in maritime ports by 2030, focusing on innovations that enhance operational efficiency, sustainability, and regulatory compliance. By analyzing these advancements, the research highlights the transformative potential of technology in port logistics and management for a future-ready maritime industry.

2. Materials and Methods

This study aims to identify key technologies and regulations in the maritime port industry. Through a cross-sectional analysis, we outline the most promising trends for technological adoption, contributing to the sector's modernization and efficiency.

Our comprehensive analysis provides an overview of future technological innovations and the regulatory frameworks guiding these changes. This study employs an organized research approach, conducting a comprehensive literature review and bibliometric analysis to examine technological advancements in maritime port facilities. In Figure A1 (Appendix A), it is possible to have a network matrix about the articles keywords analysis.

The literature review entails an organized search, categorisation by technology kinds, and synthesis of current research and publications pertinent to the maritime port industry. This methodology allows a comprehensive examination of contemporary trends and technical innovations. We examined academic journals, conference papers, and industry reports to attain a comprehensive understanding of the topic, encompassing both academic and professional viewpoints.

3. Results

This chapter delves into the rapidly evolving landscape of the maritime port industry by exploring emerging technologies, current technological trends, and the regulatory and legal frameworks governing their adoption and implementation. The integration of advanced technologies such as the Port Metaverse, Augmented Reality, Marine Robots for underwater surveillance, and many others, is revolutionizing port operations. These innovations promise significant improvements in efficiency, safety, and sustainability.

3.1 Emerging Technologies

D'Amico *et al.[2]* reveals emerging technologies such as Automated Guided Vehicles, Unmanned Aerial Vehicles, Terran360, Big Data, Cybersecurity, Virtual and Extended Reality, Digital Twins, IoT, AI, Sustainable Practices, Blockchain, Last Mile Delivery, and 3D Printing. These technologies are revolutionizing port operations, since they facilitate enhanced security through advanced monitoring and data analysis, improve operational efficiency by automating and optimizing logistics processes, and contribute to sustainability through eco-friendly practices. Applications of these technologies range from autonomous cargo handling and aerial inspections to predictive maintenance and real-time data analytics. The integration of these technologies not only reduces operational costs and minimizes human error but also fosters a more resilient and adaptive port infrastructure, paving the way for a future-ready maritime industry [2].

Recent advancements in technology have transformed port operations, improving efficiency, safety, and sustainability. Automated Guided Vehicles (AGV) have become essential instruments, functioning independently in port settings to optimise cargo handling and transportation, consequently lowering labour expenses and operational hazards [2]. Unmanned Airborne Vehicles, or drones, are increasingly employed for airborne inspections and surveillance, facilitating swift and secure data acquisition for infrastructure monitoring and disaster response [2] [3].

Terran360, an advanced navigation and mapping technology, enhances vehicle manoeuvres within ports, guaranteeing precision and safety in operations [4]. The emergence of Big Data Analytics has for extensive data collection and analysis, enhancing predictive maintenance and operational forecasting, essential for strategic decision-making [5]. Cybersecurity measures are essential to defend port IT systems from cyber assaults, hence protecting vital infrastructure and sensitive data [6].

Virtual and Extended Reality (VR/ER) technologies provide immersive training simulations and remote maintenance functionalities, greatly improving operational safety and decision-making processes [6]. Digital Twins, as virtual duplicates of actual port systems, offer a comprehensive framework for system monitoring, predictive maintenance, and scenario planning, enhancing operating efficiency and minimising downtime [2] [7].

The Internet of Things (IoT) interlinks devices for instantaneous data sharing, improving transparency and operational efficiency throughout the supply chain [5]. Artificial Intelligence (AI) facilitates automation and sophisticated data analysis, enhancing performance and enabling informed decision-making [8]. The implementation of sustainable practices, such as the use of renewable energy and waste minimisation strategies, is crucial for reducing environmental impact and realising financial benefits [9].

Blockchain technology provides a decentralised ledger system that improves supply chain transparency, safeguards transactions, and optimises documentation processes [10]. Last Mile Delivery solutions concentrate on enhancing the final segment of transportation, guaranteeing expedited and more economical delivery [11]. Ultimately, 3D printing technology facilitates on-demand fabrication of bespoke components, minimising lead times and production expenses, while enhancing customisation in port operations [11].

Additionally, this structured presentation aims to enhance understanding and provide a clear, concise summary of the complex and multifaceted aspects of integrating innovative technologies into the maritime port industry, thereby supporting informed decision-making for stakeholders.

3.2 Technology trends beyond 2030

The supply chain has undergone significant changes due to advancements in technology. The Port Metaverse concept, a digital replica of port settings, enables virtual simulations, remote operations, and training [11]. Augmented Reality enhances operational efficiency by superimposing digital information onto the physical environment [11]. Marine robots, autonomous systems for underwater surveillance, and Next-Generation Humanoid Working Robots enhance efficiency and reduce labour costs [6]. Machine Customers automate transactions and refine demand forecasting, optimizing operations [11]. Composite AI provides predictive analytics, decision support, and automation, enhancing decision-making and operational efficiency [11]. Augmented-connected workforce enhances human-machine collaboration, while AI-Enabled Vision Systems improve quality control and security surveillance [6]. Cyber extortion measures prevent cyber ransom threats and ensure data integrity. Supply Chain Data Governance ensures data integrity and compliance [8], while End-to-End Sustainable Supply Chains emphasize sustainability, integrating eco-friendly logistics and waste minimisation strategies [6].

3.3 Regulatory and Legal Regulations

Responsibility for ensuring ships comply with international safety, pollution prevention, and living and working conditions primarily lies with the flag State. The flag State guarantees the effectiveness of inspections and surveys for relevant certificates, relying on recognized organizations as needed. However, many flag States neglect to comply with international standards [12].

As a secondary defence against non-compliant ships, Port State Control (PSC) ensures compliance to international standards for safety, pollution prevention, and living and working conditions on board. PSC inspections do not replace flag State responsibilities [12].

The regulatory framework overseeing port operations is essential for maintaining safety, security, and sustainability. Personal Privacy Regulations govern data gathering and utilisation, together with surveillance systems, to safeguard individual privacy and maintain data security [13]. Airspace Control and Limitations regulate the utilisation of Unmanned Aerial Vehicles, mitigating airspace congestion and maintaining safety [14].

Regulations of the International Maritime Organisation emphasise marine environmental protection and safety requirements, assuring adherence to global benchmarks and improving safety [15]. Port State Control (PSC) Regulations pertain to the inspection and oversight of foreign vessels, hence augmenting marine safety and mitigating poor shipping practices [12].

European Union regulations for ports and technologies advocate the adoption of technological and environmental standards, encouraging innovation and maintaining sustainability [16]. Cybersecurity regulations safeguard IT systems and maintain data integrity, hence augmenting security and thwarting cyberattacks [8].

Environmental ID Emission Regulations govern emissions from port operations, mitigating environmental effects and fostering sustainability [8]. Blockchain and Data Governance Regulations guarantee secure transactions and efficient data management, improving data transparency and integrity [16].

Artificial Intelligence and Automation Ethics Regulations oversee the application of AI and robotics in port operations, ensuring ethical utilisation and fostering responsible innovation [8]. Sustainable Practices Mandates promote the implementation of environmentally friendly technology and practices, minimising carbon footprints and advancing green logistics [15].

4. Conclusions

In conclusion, this study underscores the critical importance of data research in advancing the maritime port industry. The careful analysis of emerging technologies and their applications not only enriches the academic discourse, but also provides invaluable insights for industry practitioners. The results of this research can serve as a solid foundation for knowledge sharing and benchmarking within the maritime port sector, providing a comprehensive understanding of current trends and future innovations.

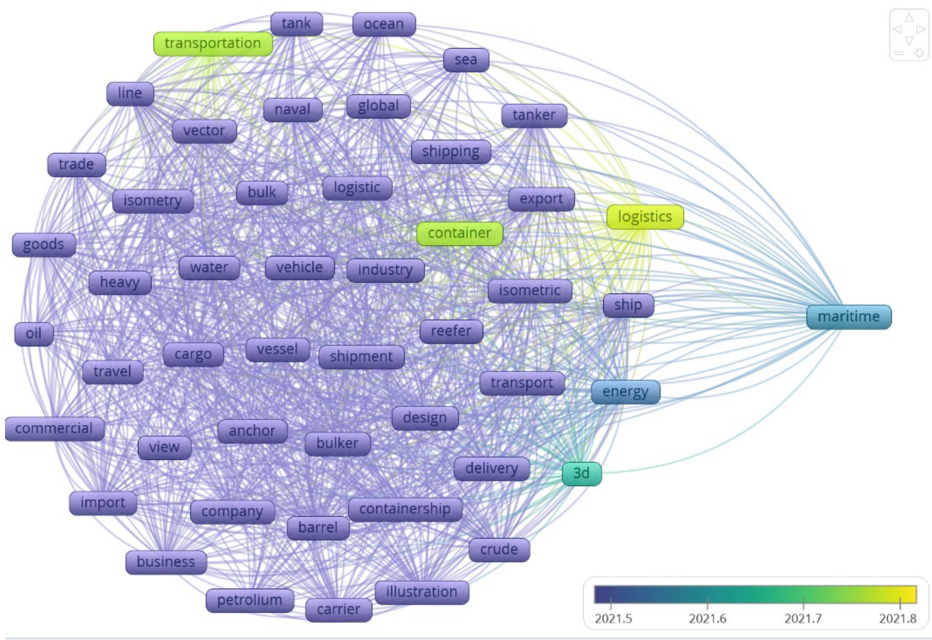
In addition, the relevance of this study extends beyond the maritime port industry. Other sectors can adapt the identified technologies and trends to improve their own operations, increase efficiency and foster innovation in various fields. The ability to transfer these findings across industries underscores the versatility and far-reaching impact of the research.

Maintaining an up-to-date repository of technology data is critical given the rapid pace of change in today's world. Continuously tracking and documenting advances ensures that stakeholders remain informed and prepared to implement new solutions as they emerge. This ongoing vigilance is essential to staying ahead in a competitive landscape and maximizing the benefits of technological innovation.

Finally, the relevance of this study lies not only in its immediate findings, but also in its potential for future updates. As the industry evolves, revisiting and expanding this research will be critical to capturing new developments and sustaining progress. By keeping this research dynamic and responsive to change, it will continue to provide significant value to the seaport industry and beyond.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53)

Appendix A Table A1 Bibliometric Analysis



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Integrating Lifelong Learning Within R&I Projects: The case study of the NEXUS

Fabianne Ribeiro[1*] and António Neves[1]

[1]IEETA- Institute of Electronic Engineer and Informatics, University of Aveiro, Campus Universitário de Santiago, Aveiro, Portugal.
*Correspondence: ribeiro.f@ua.pt

Abstract: Lifelong learning has emerged as imperative within contemporary organizational contexts, covering both small and medium-sized enterprises as well as expansive industrial sectors, largely attributable to the impacts of the ongoing digital transformation. Given the present landscape characterized by an escalating digital transformation, employers confront the imminent risk of job displacement, thereby compelling organizations to cope with the necessity of sourcing and training human resources equipped with the requisite proficiencies tailored to the demands of cutting- edge technologies. Research & Development (R&D) projects, led by High Education Institutions (HEIs), often in collaboration with an array of stakeholders, have the advantage of making use of the HEIs facilities, cutting edge equipment and up-to-date knowledge, to foster human resources capacitation within the project. Through mutual collaboration, HEIs can design customized capacity-building programs that are aligned with the specific requirements and operational context of the involved stakeholders, consequently facilitating the promotion of employee upskilling and reskilling activities. This integrated process serves to ensure the seamless transference of knowledge gathered during the course of R&D projects into the industrial domain, perpetuating the cycle of lifelong learning and skill development among the workforce. This paper is intended to present the work in progress developed under a national project aiming at the digitalization of the logistics sector in Portugal. Counting with approximately 35 companies in the supply chain sector, the project includes a work package for capacity building of the employees. The goal is to upskill and/or re- skill employees so they can be capacitated to deploy the new technologies needed by the companies to fulfill their goals of products and services creation.

Keywords: Lifelong learning, upskill, adult education

1. Introduction

The later global pandemic exerted varying degrees of impact across all economic activities. The logistics sector appeared as one of the most affected industries. In this context, the logistics sector recognized the acute need for business digitalization, a process already underway but markedly accelerated by the exigencies imposed during the pandemic [1]. From 2020 to nowadays, there has been an exponential increase in the number of scientific papers published in the subject of digital transformation on logistics.

The digital transformation of an organization implies the adoption of novel technologies. These technologies will enhance the manner the company provides its services, encompassing improvements that are a necessity today, such as increased transparency in transactions, task automation, data-driven decisions, high efficiency, cost reduction and environmental sustainability.

Nevertheless, the adoption of emerging technologies is also associated with the need for human competences to operate new systems. One of the biggest challenges for digital transformation in companies is precisely the skill gap existing among employees to work with these new technologies [2,3]. Consequently, organizations are faced with a dual dilemma: either invest in upskilling or reskilling existing personnel or endeavor on the recruitment of new staff. While several companies exhibit awareness of the importance for continuous training of their workforce, unfortunately, most organizations, especially small and medium sized enterprises (SMEs) remain negligent in this regard.

Additionally, the literature highlights various challenges associated with employee reskilling/upskilling. These include employee resistance to change, the financial burden on the company for training, the absence of the employee during the training period, and, finally, the imminent risk of losing an employee in whom the company has invested for qualification improvements [4–6].

This paper is intended to present the work in progress developed in the context of the WP9 of the NEXUS Agenda – Advanced Capacitation & Training of Human Resources. The purpose of this work package is to upskill and/or re-skill employees so they can be capacitated to deploy the new technologies needed by the companies to fulfill their goals of products and services creation and future utilization. Simultaneously, our goal is to shed light on the pivotal role played by higher education institutions (HEIs) in the realm of lifelong learning while analyzing the associated advantages and drawbacks.

2. Materials and Methods

The objective of our training and requalification workpackage within a research and innovation project is to train and enable employees from the consortium companies to apply the necessary competences for each member to develop the products and services expected within the scope of the project. The final product of this work package is the NEXUS Academy – A training academy tailored to the needs of the logistics sector at a European level, which will deliver detailed courses to tackle the challenges of digital and green transformation in the logistic sector, and which is intended to continue to operate after the project is completed. In this way, not only can the project deliver research and innovation, but its findings can be perpetuated through lifelong learning of the workforce involved in the thematic area of logistics.

To create the nexus academy, we implemented a methodology, that was divided in three distinct phases: 1) desk research of the technological trends for the digital transformation of the logistics sector, 2) the identification of training courses already available at the HEIs associated with the project and 3) a questionnaire addressed to companies, followed by an interview section, to realize which skills they require to develop the product and services proposed in the project.

Having completed those three steps, the following phase will contemplate the creation of the missing training offer in the HEIs.

3. Results & Discussion

As this research is still in progress, we will herein delineate the achieved results and discuss identified limitations and challenges. Figure 1 illustrates the primary findings derived from desk research, emphasizing the escalating number of publications related to digital transformation in the supply chain sector (A) and outlining the pivotal technologies identified for the future of logistics (B). The desk research findings have been disseminated internally as a project deliverable, intending to guide partners in discerning training needs during interview sections.

A questionnaire was disseminated to all project company members to comprehend their training requirements. Unfortunately, the questionnaire received a notably low participation rate (28.5%), attributable to internal challenges within SMEs in identifying their training needs. Similar challenges have been acknowledged by other scholars, with contributing factors including restricted budgets for employee training, employee unavailability, and managerial deficits in digital literacy and vision of the future [3,7].

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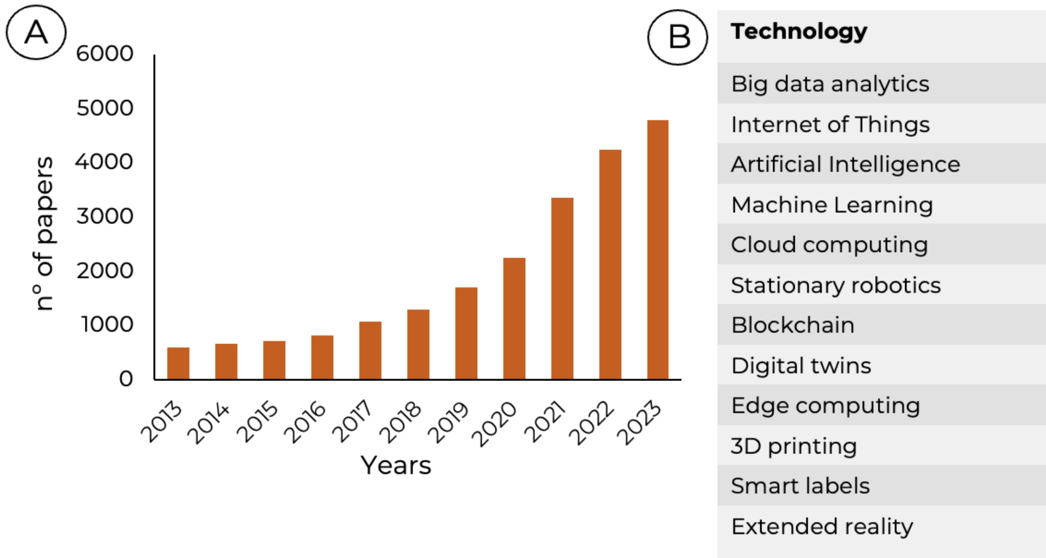

Figure 1. A –Number of papers published in the last 10 years, withdrawn from Science Direct using the keywords "Digital AND transformation AND supply chain. B – Summary of the main technology found in the desk research as relevant for the future of logistics

In response to these outcomes, a document associating each proposed product and service with the required skills for its development was created. This document was proactively sent to companies prior to the interview sessions, wherein we solicited responsible personnel to validate or modify the identified skills for each product and service. This approach proved more efficient in expediting the identification of skill gaps in companies, resulting in an increased participation rate compared to the questionnaire (3 out of 5 companies responded thus far) and facilitating the identification of skill gaps in conjunction with the interview sections.

Figure 2 summarizes the outcomes of interview sections conducted with three companies, each associated with the development of products within distinct scientific domains. The subsequent phase of this research entails the initiation of an academy designed to deliver specific training content for companies associated with the project. Additionally, this academy is envisioned to serve as a reference center for lifelong education in the scientific domain of digital logistics.

Company	Scientific area of research and innovation	Required training
A	Smart logistics AI-powered applications Green ports	• Foreign trade • Project management • Environmental indicators platform management • Accounting software • Transition from fuel to electric engines • Carbon footprint management
B	Technology developer	• Technology applied to logistics • Software certification • Programming skills • Project management
C	Logistic operator	• Software development and operation (DevOps) • Software operation for filling out waybills

Figure 2. Summary of the 3 interviews conducted with project members and the required training for the development of innovative products proposed in the project.

Notably, the research engaged human resources professionals with over two decades of experience in the technology and logistics sector. All interviewees underscored the absence of specific training offerings tailored to technology in logistics, both in higher education institutions (HEIs) and private business schools. This discovery underscores the imperative need for an effective communication strategy between HEIs and industry stakeholders.

5. Conclusions

Despite being a work in progress, the preliminary results lead us to conclude that there is substantial potential in integrating human resources training within research and development projects, particularly when developing solutions aligned with industry needs. Furthermore, we posit that establishing closer ties between industry and academia is a fundamental factor in fostering the practice of lifelong learning—a nascent trend in our society but indispensable for economic and social growth.

Author Contributions: Conceptualization, A.N and FR methodology: AN and FR, validation: AN; resources: AN; writing—original draft preparation: FR; writing—review and editing: AN and FR; project administration: AN; funding acquisition: AN

Funding: This study was funded by the PRR - Recovery and Resilience Plan and by the NextGenerationEU funds at Universidade de Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovacão – Transição Verde e Digital para Transportes, Log ística e Mobilidade" (Project no.53 with the application C645112083-00000059).

Data Availability Statement: Data is available upon authors request.

Conflicts of Interest: Authors have no conflict of interest to declare.

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A decision support system for planning and scheduling port operations: conceptual architecture

Catarina C. Carvalho [1,*], Seyed Mahdi Homayouni [3], Jorge Pinho de Sousa [1,2], Catarina M. Marques [1], Ana Maria Rodrigues[1]

[1] INESC TEC, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[2] Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[3] Constructor University Bremen gGmbH, Campus Ring 1, 28759 Bremen, Germany
* Correspondence: catarina.c.carvalho@inesctec.pt

Abstract: The effective organization and coordination of port operations are essential for reducing costs and lead times, while maintaining customer service levels and adhering to environmental standards. This paper presents a conceptual architecture for a Decision Support System (DSS) that integrates simulation, and optimisation approaches to coordinate logistic operations in ports. The DSS addresses several key challenges of port planning activities, including the scheduling of quay and yard cranes, and the deployment of intra-port vehicles. It places particular emphasis on the synchronisation of these activities, with the objective of enhancing overall efficiency. By leveraging advanced scheduling techniques and optimisation algorithms, the system optimizes the movement of containers between ships and storage yards, with a particular focus on the effective utilization of intra-port vehicles such as yard trucks and automated guided vehicles (AGVs). The proposed architecture provides a comprehensive framework for decision-making, offering a holistic view of port logistic operations, and bridging the gap between specific problem focused research and integrated system solutions. This approach aims at enhancing the efficiency and synchronisation of port activities, thereby fostering more informed and effective decision-making in port logistics management.

Keywords: port operations; container terminals; decision support systems; hinterland transportation; vehicle scheduling.

1. Introduction

Planning and scheduling port operations is a complex task involving the coordination of container movements and the use of different types of resources. The main goal is to improve the overall efficiency of the port logistic operations, by reducing costs and times, while meeting customer service levels and environmental requirements. In this context, there are multiple planning problems such as the allocation of ships to berths, quay crane scheduling, yard crane scheduling, and yard truck scheduling, as well as the connection to the hinterland transportation systems.

However, achieving an effective integration and synchronisation of most of these activities is quite complex, as highlighted by most of the literature in the area. Much research work has focused on specific, fragmented problems, without a global perspective of the system.

In container terminals, vehicles play a critical role in the movement of containers between ships and the Storage Yards (SYs). To streamline this process, scheduling methods are employed, determining the sequence, routing, and assignment of vehicles, for the loading/unloading tasks. Tang et al. [1] propose a Particle Swarm Optimisation (PSO) algorithm, coupled with a heuristic procedure, for the joint scheduling of Quay

Cranes (QCs) and Automated Guided Vehicles (AGVs). More recently, a bi-objective version of the problem has been proposed by Fontes et al. [2] to solve the joint scheduling of QCs and speed-adjustable vehicles.

In this context, the SY can be viewed as a crucial buffer zone, bridging maritime transportation and land transportation modes. Storage yard management is a complex challenge, usually modelled mathematically by the so-called Storage Space Allocation Problem (SSAP). The primary objective of the SSAP is to efficiently allocate temporary storage "blocks" for incoming and outgoing loads, to minimize the time it takes to store and retrieve loads. Vis et al. [3] introduced the innovative concept of buffer zones within the transfer quay-storage yard, having developed a Mixed-Integer Linear Programming (MILP) model to determine the minimum fleet size required to ensure that each container is transported within its specified timeframe.

Moreover, as the port's hinterland operations are highly dynamic, most research work has focused on the management and coordination of inter and multimodal transport networks. Although intermodal transport networks have been studied for decades, port-hinterland transport still entails considerable management challenges. In this regard, several optimisation approaches have been developed over the years, mostly focusing on reducing logistic costs and lead times. Caris et al. [5] developed a MILP model for the design of intermodal barge transport networks, to minimize the total transportation costs. More recently, Gumuskaya et al. [6] addressed the planning barge hinterland transport problem, considering uncertainty in the arrival times of containers.

The growth in freight transportation and intermodal network systems has also intensified traffic in urban port areas, leading to new challenges for vehicle routing and scheduling in port/hinterland connections. To efficiently tackle these challenges, Heggen et al. [7] worked on a new integrated intermodal routing problem, addressing the routing of containers and trucks throughout the network, with a heterogeneous truck.

According to Sánchez-Cervantes et al. [8], the growing complexity of port logistics requires objective decision-making supported by analytical methods. Integrating these methods into DSS enables effective computation, addressing diverse operational challenges. Mokhtari et al. [9] propose a DSS for risk management in seaports and terminals. Caris et al. [10] developed a DSS for intermodal transport addressing policy support, network design, routing, and ICT innovations, focusing on the role of these aspects in optimizing operations.

In this context, this research aims to develop a conceptual architecture for a DSS, based on simulation and optimisation methods, to effectively coordinate and synchronize logistic operations in the container terminals, storage yards, and the hinterland. The main contribution of the work is, therefore, the development of a conceptual model providing an integrated overview of the port logistic operations, thus supporting more informed decision-making processes.

2. Materials and Methods

This work aims to explore the links between three key port logistic problems, integrating their resolution into a single DSS (Figure 1), namely: i) intra-port operations scheduling and Yard Crane (YC) synchronisation; ii) container allocation to the SY; and iii) hinterland truck routing.

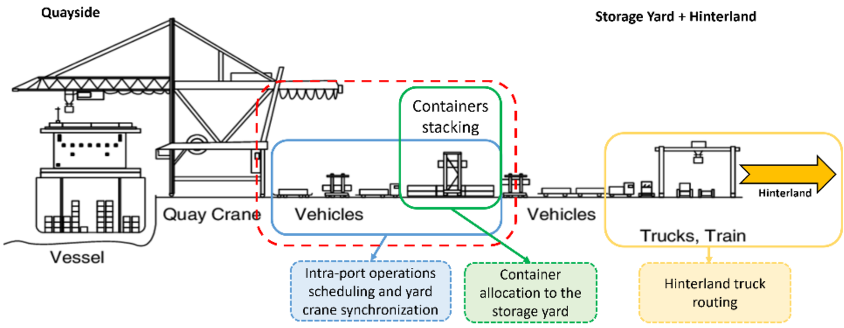

Figure 1. Scope of the analysis.

Given the distinct nature of these issues and the related objectives, the key challenge lies in understanding the interface between the hinterland and the port operations. This requires high coordination between port activities and hinterland logistics partners, based on the information flows between both settings.

The first part of this DSS will be based on an optimisation model that synchronises the schedules of QCs and AGVs operations (including AGVs recharge tasks), to minimize task completion times and unproductive movements of vehicles. Optimal plans will result in lower ship release times and more energy-efficient operations. The second part of the process aims at synchronizing the AGVs with the SY and the hinterland operations. Here, the goal is to allocate the containers to specific positions in the yard, to minimize the waiting and idle times of the AGVs, the global energy costs, and the lead times.

Finally, optimizing hinterland truck routing is essential to complement the synchronisation of yard operations. This problem usually involves the selection of routes, types of vehicles, and quantities to be transported. In this case, the goal is to select the routes and the transportation modes, to optimise, in a multi-criteria perspective, the transport activities from the container terminals to the destination. The route optimisation is based on information on distances, delivery (promised) dates, and the speed of the vehicles.

Historical data will be used for an initial assessment of the DSS effectiveness in addressing port logistics challenges. Then, real-world data will be used, enabling a more robust evaluation of the tool's performance under realistic conditions. This approach will ensure that the tool is not only theoretically sound but also applicable in real-world operational contexts.

3. Main Results

Based on the detailed investigation of the port's internal and external processes, the main outcome of this work is the DSS conceptual architecture. The DSS is structured into two modules (Figure 2): the first module has two components and will address intra-port operations scheduling and YC synchronisation, and the allocation of containers to the SY; and the second module will optimise hinterland truck routing.

The outputs of the first module will serve as the basis for creating the routes of hinterland trucks and trains, from the container terminals to the end customers.

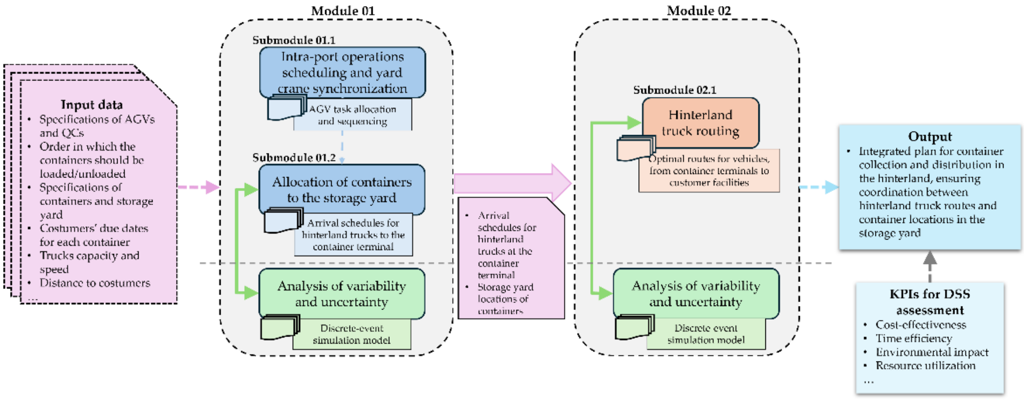

Figure 2. DSS architecture.

3.1. Module 01: operations scheduling and allocation of containers to the storage yard

This module focuses on optimising the scheduling of intra-port operations and the containers allocation to the SY. By synchronizing the activities of AGVs and YCs, the goal here is to reduce idle times, energy costs, and lead times, ensuring efficient container handling and timely deliveries.

3.1.1. Intra-port operations scheduling and YC synchronisation

Here, the problem is modelled as a bi-objective MILP, and a heuristic-based approach is used to solve large-scale instances. Decisions are made on the assignment of tasks to the AGVs, and the respective tasks sequences, to minimize task completion times and unproductive movements of AGVs. To efficiently tackle real-world instances, an approach based on the well-known Non-dominated Sorting Genetic Algorithm II (NSGA-II) is being developed.

3.1.2. Allocation of containers to the SY

As in the case of the previous sub-module, an exact optimisation approach will be used together with a heuristic-based approach for large-scale instances. Here the main input data will include the SY layout and capacity, container features (size, weight, destination, and priority) as well as the output of the previous sub-module, including the sequence of tasks to be performed by each AGV.

The goal of this procedure is to determine the YC schedule, synchronized with the schedules of AGVs and hinterland trucks, as well as the containers assignment to SY locations, to ensure on-time delivery to customers.

Finally, a discrete event simulation approach will be integrated with the optimization component to tackle uncertainty and better capture the system's dynamics.

3.2. Module 02: hinterland truck routing

To address this problem, another MILP model is being developed. This model will be used to assign a set of "orders/transportation services" to specific routes and transportation modes, aiming at minimizing the total delivery times and costs.

As input data, we are assuming to have access to information on the sequence of arrival of hinterland trucks at the container terminal: the customers (locations, delivery time windows, and delivery priorities); the vehicles (capacities, speed, and availability); the road network.

The main goal of this procedure is to determine:

- the optimal routes for vehicles, from container terminals to customer facilities, considering distances, delivery time windows, and vehicle speeds (in a multi-criteria perspective);

- the assignment of containers to trucks, based on their capacities and the delivery requirements.

As in the case of module 01, a simulation model will complement the optimisation procedure, as a way to address the uncertainty and to provide insights on possible system disruptions of various natures, thus supporting the planning process.

4. Discussion

The main purpose of the Decision Support System presented in this paper is to enhance port logistics and hinterland operations, with a strong emphasis on the optimisation of hinterland vehicle routing, in a multi-criteria perspective. This entails prioritising factors such as cost-effectiveness, time efficiency, environmental impact, and resource utilization, to ensure the most efficient and sustainable transportation routes.

The system also aims at minimising energy costs associated with AGVs, by reducing waiting times and energy consumption. Significative reductions are also expected in the times for loading/unloading tasks. These reductions can be achieved by synchronising the AGVs with the yard cranes and the outside vehicles, thus enhancing resource utilisation, and improving service levels. The next research steps include the validation of this architecture in a real-world setting.

Author Contributions: Conceptualization, C.C., M.H., J.P.S., C.M., and A.R.; methodology, C.C., M.H., J.P.S., C.M., and A.R; software, C.C., and M.H.; validation, C.C., M.H., and C.M.; formal analysis, C.C., M.H., C.M. and A.R.; investigation, C.C., M.H., J.P.S., C.M., and A.R; data curation, C.C., and C.M; writing—original draft preparation, C.C.; writing—review and editing, J.P.S., C.M., and A.R; supervision, J.P.S., C.M., and A.R.; project administration, J.P.S.; funding acquisition, J.P.S. All authors have read and agreed to the published version of the manuscript.". Authorship must be limited to those who have contributed substantially to the work reported.

Funding: This research is co-financed by Component 5 – Capitalization and Business Innovation, integrated in the Resilience Dimension of the Recovery and Resilience Plan, within the scope of the Recovery and Resilience Mechanism (MRR) of the European Union (EU), framed in the Next Generation EU, for the period 2021 – 2026, within project NEXUS, with reference 53.

Data Availability Statement: No new data were created.

Acknowledgments: NA

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Towards Equipment Operations Optimization through a Novel Efficiency Analysis Model

Syed M. Kazmi[1], Eugénio M. Rocha[1,3], Ângela F. Brochado[2,3]

[1]University of Aveiro, 3810-193 Aveiro, Portugal:[1]Department of Mathematics (DMat),
[2]Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT),
[3]Center for Research and Development in Mathematics and Applications (CIDMA)

Abstract: Efficient port operations are vital for economic growth and supply chain reliability, so having precise and realistic models for measuring efficiency is essential for decision-making, optimizing logistics, reducing costs, sustainability, and enhancing global trade competitiveness. The focus of this work is the performance analysis of some equipment operations of the Port of Sines. Within the mathematical field of efficiency evaluation and benchmarking analysis, methodologies like Stochastic Frontier Analysis, Data Envelopment Analysis (DEA), and most recently, Multi-Directional Efficiency Analysis (MEA), have been instrumental. MEA can be considered an improvement over DEA due to its strength in producing inefficiency scores for each variable and decision-making unit. The literature offers several variants of these methodologies, but a major limitation has not been addressed: the requirement for a linear scaling relationship between inputs and outputs. This assumption contradicts the law of diminishing returns, which states that increasing inputs eventually leads to smaller output gains and potential plateaus. To meet this gap, the authors propose a new MEA's variant model with desirable and undesirable outputs employing nonlinear scaling functions to capture more realistic relationships between inputs/outputs. To define those functions in a particular context, data-driven techniques are used. The cargo movement operations in the Port of Sines are studied to demonstrate its usefulness in real-world situations.

Keywords: Port operations, equipment planning, sustainability, nonlinear modeling, efficiency evaluation.

1. Introduction

The global logistics sector is at a critical point, facing the challenges of becoming both green and digital. Sustainable and efficient port operations are essential for environmental health and economic growth. Benchmarking is a powerful technique that allows logistics stakeholders to compare their performance against industry best practices. By analyzing these comparisons, ports can identify areas for improvement and implement strategies to optimize efficiency, minimize environmental impact, and ultimately contribute to the Green and Digital Transition. In fact, in the Green Transition context, benchmarking helps ports move towards sustainability in several ways [1]. It allows ports to identify emission reduction strategies by comparing CO_2 emissions and energy consumption with industry leaders. By pinpointing areas for improvement, ports can implement targeted strategies to reduce their environmental footprint. Additionally, benchmarking cargo handling efficiency and resource utilization (e.g., energy, fuel) helps ports adopt more sustainable practices, such as using energy-efficient equipment and optimizing operational procedures. Moreover, the effectiveness of green technologies like shore power or electric vehicles can be assessed through benchmarking, enabling ports to make informed decisions about adopting these technologies and maximizing their impact.

From a different perspective, digital transition unlocks a wealth of opportunities for port efficiency and environmental sustainability. Benchmarking plays a crucial role in this by enabling ports to assess digitalization maturity by comparing their level of digitalization (e.g., automation, real-time data analytics) with industry leaders, hence can identify areas where they can leverage digital technologies to optimize operations. The concept of benchmarking can also be applied to recommender systems, which are algorithms that suggest items to users based on their past behavior or preferences. A recent study by Qijiong Liu et al. [2] proposes a Green AI benchmarking framework, known as GreenRec, for news recommender systems. GreenRec incorporates an efficient only-encode-once (OLEO) paradigm that achieves competitive accuracy while significantly reducing energy consumption compared to traditional training methods. By establishing robust benchmarking practices, port authorities can gain valuable insights to propel their operations towards a greener and more digitally driven future.

Mathematically, traditional methods used for evaluating port performance often fall short. They fail to capture the complex interplay between economic efficiency and environmental impact. This requires advanced performance evaluation tools that can simultaneously assess multiple aspects of port operations. While traditional Data Envelopment Analysis (DEA) models, commonly used for efficiency assessment and benchmarking, have found widespread use for efficiency assessment and benchmarking [3], they rely on linear relationships between inputs and outputs. These models, despite their application in green logistics within China and third-party logistics in France [4, 5], often fall short when applied to real-world port operations. While newer tools like Multi-directional Efficiency Assessment (MEA) have emerged to address the limitations of traditional DEA models, especially in the environmental domain [6], they inherent nonlinearity of such operations and hence lead to inaccurate efficiency estimates and hinder the development of effective improvement strategies. To address this issue, in this work the so-called Nonlinear Multi-directional Efficiency Analysis (nMEA) model is proposed and applied to data regarding equipment operations at the Port of Sines.

2. Material and Methods

The new nMEA model was developed to incorporate nonlinear dependencies through distinct functions that capture relations between inputs and outputs and offer a more realistic representation of processes variations, particularly when dealing with environmental considerations like energy consumption and emissions. This model was then used to study the efficiency of equipment operations on the Port of Sines, Portugal, a major European port handling diverse cargo types.

The following steps outline the methodology for the equipment operations study:

- **Data Collection**: Comprehensive data was collected on the performance of various port equipment units (Gantry Cranes) for a period of four years (2021-2024). This data included cargo handled operational time, energy consumption, and CO2 emissions (where the latter two factors were estimated using established conversion factors for energy consumption per hour unit and CO2 emissions per energy unit).
- **Model Development and Adjustment:** The nMEA model was adapted to the specific data context of the Port of Sines. This involved defining relevant desirable outputs, undesirable outputs, and resource inputs for the chosen equipment units. To capture nonlinearity links, the best curve fit function was identified for each year and each individual desirable and undesirable output. Subsequently, a four-stage optimization process was employed, as in Standard MEA, to minimize input usage,

maximize desirable outputs, minimize undesirable outputs, and optimize slack variables, thereby achieving an optimal operational strategy for the port.

- **Efficiency Score Calculation:** The nMEA model was applied to the data to calculate efficiency scores for each equipment unit across each year. These scores represent a single metric encompassing all considered efficiency dimensions, allowing for a holistic evaluation of port performance, and have values between zero and one, where one means top (relative) efficiency.

Finally, the obtained efficiency scores were compared and discussed.

3. Main Results

The application of nMEA model yielded valuable insights into the performance of the Port of Sines, highlighting specific areas where the port could improve its efficiency and sustainability. The analysis focused on 13 unique equipment types categorized as Gantry cranes. These cranes were operational for varying periods between 2021-2024 and their annual performance is described in Figure 1.

The study revealed several interesting trends in crane efficiency. Briefly, in 2021, QC04 stood out as the leader with a score of 0.76, while all other cranes except QC10 exceeded an efficiency of 0.40. It should be noted that cranes are linearly aligned and obstruct each other. However, 2022 saw a shift, with crane efficiencies generally clustering around 0.40 to 0.60. Notably, GRUA LIEBHERR 40T dipped to an efficiency of 0.31. This trend continued in 2023, apart from GRUA LIEBHERR 40T again underperforming. Interestingly, 2024 saw the introduction of QC12, which quickly achieved the second-highest efficiency score of 0.50, just behind QC03. It also shows a change in utilization strategy. Briefly summarizing, these efficiency scores are influenced by many factors beyond the cranes themselves. For example, the complexity of the tasks they handle, the schedule of shifts, the experience of the operators, and overall site conditions play a role. As is largely known, COVID-19 caused significant delays and bottlenecks in global supply chains due to reduced workforce, but also led to a surge in container shipping costs, driven by high demand for goods and limited container availability. Such phenomena propagated over the following years and may also have influenced the operations of the Port of Sines.

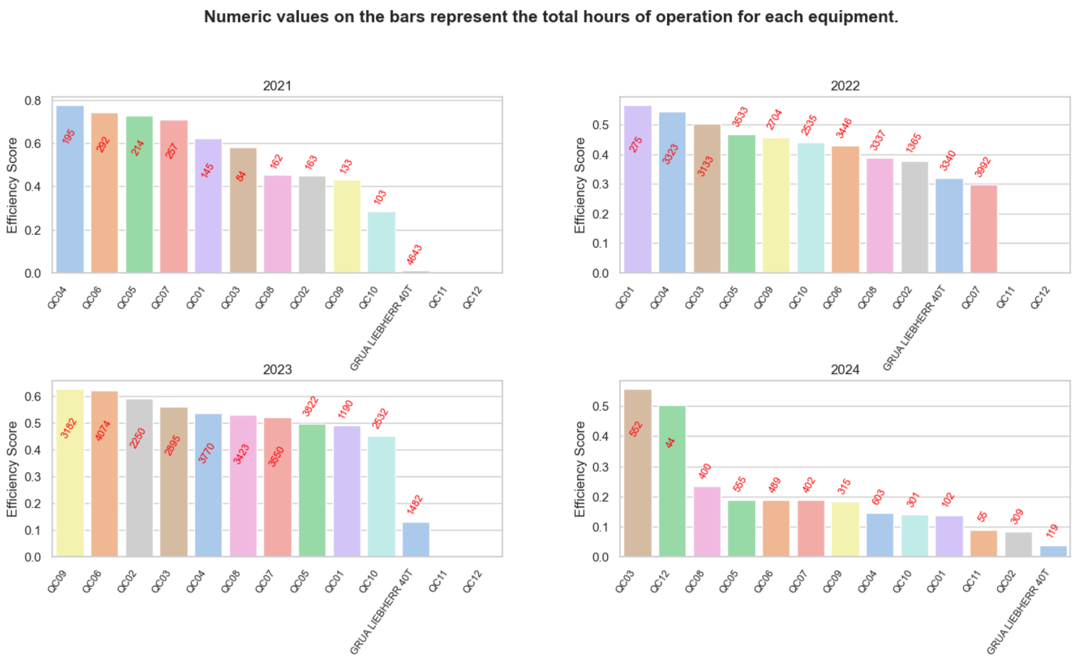

Figure 1: Average Efficiency scores of unique Gantry Cranes .

4. Conclusions

This study explores the applicability of a new algorithm to evaluate the efficiency of equipment in the Port of Sines. By analyzing data from 2021 to 2024, it was possible to gain insight into the efficiency trends of Gantry cranes, along with their potential for energy savings and CO_2 emission reduction. Looking at the overall efficiency across equipment categories, it is evident that no equipment achieved an average score above 0.80 from 2020 to 2023, with most scores remaining below 0.60 within their respective years. However, with limited data available for 2024, initial indications suggest that equipment efficiencies are below 0.20, with some exceptions. These findings highlight the significant potential for energy conservation and CO_2 emission reduction within the Port of Sines by adopting some usage strategies. The prevalence of under-performing equipment underscores the need for targeted interventions to improve overall efficiency. This could involve strategies such as optimizing operational practices, implementing preventive maintenance programs, or even investing in environmentally friendly equipment technologies. Furthermore, stricter government policies promoting sustainable practices and energy-efficient equipment usage would further contribute to the Port's environmental goals.

In general, this study also demonstrates the effectiveness of the nMEA model approach in assessing the efficiency of port equipment. Identified inefficiencies and potential for improvement can inform targeted strategies to optimize equipment performance, leading to more sustainable and environmentally friendly port operations, contributing to a greener future for the maritime industry.

Acknowledgments. The present study was developed within the scope of the "Agenda NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. 53).

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Combining 5G Network Slicing and Computer Vision in ITS

Rui Silva[1*], David Santos[1], Filipe Antão[1], André Perdigão[1], Fatma Marzouk[1], Daniel Corujo[1] and Rui L. Aguiar[1]

1 Universidade de Aveiro, Portugal.
E-mail: ruimiguelsilva@ua.pt; davidsantos@ua.pt; fantao@ua.pt; andreperdigao@ua.pt; fatma.marzouk@ua.pt; dcorujo@ua.pt; ruilaa@ua.pt

* Correspondence: ruimiguelsilva@ua.pt

Abstract This paper presents an energy efficient system leveraging 5G dynamic network slicing and containerized computer vision to adaptively manage resources for real-time high-resolution object detection. Initially, a camera transmits a low-quality video stream over 5G to a container running a lightweight computer vision algorithm for truck detection. Upon detecting a truck, a new container with Graphical Processing Unit (GPU) acceleration is instantiated, and a high-definition 4K video stream is initiated via a dedicated 5G network slice to ensure optimal bandwidth. This high-resolution stream enables a more sophisticated computer vision algorithm to accurately detect and read the truck's license plate. After successfully processing the license plate, the system deallocates the GPU container, terminates the 4K stream, and releases the network slice, thus optimizing resource utilization. The system is flexible and can be reconfigured to detect other objects such as marine container IDs or hazard symbols. Experimental results demonstrate the system's efficiency in balancing resource usage and energy consumption while maintaining high accuracy. This approach highlights the potential of integrating 5G technology with containerization to enhance real-time computer vision applications in intelligent transportation systems.

Keywords: 5G and beyond, network slicing, containerization, resource management, energy efficiency, intelligent transportation systems, computer vision

1. Introduction

The advent of 5G and beyond technologies promise significant advancements in connectivity, offering high bandwidth, low latency, and improved reliability. These features are particularly beneficial for real-time applications, including those in the field of intelligent transportation systems (ITS) where timely and accurate information processing is crucial. Computer vision, a critical component of ITS [1][2], can benefit immensely from 5G's capabilities, enabling high-resolution video processing and real-time data analysis while promoting the efficient usage of both networking and computing resources.

Traditional computer vision systems for tasks such as license plate recognition often struggle with limitations in network bandwidth and computational resources, especially when scaling to high-definition video streams. These limitations can result in latency issues and increased costs due to the constant high demand for processing power and network capacity. To address these challenges, we propose a system that dynamically allocates both the 5G radio resources and the computational resources based on the real-time needs of the application.

Our system initially employs a low-quality video stream (360p) transmitted over 5G to a containerized computer vision algorithm tasked with detecting the presence of trucks. Once a truck is detected, the system dynamically instantiates a new container equipped with GPU resources and establishes a 4K video stream through a dedicated 5G network slice. A full video stream is required to be established since there are many variables, such as the truck's position, reflexions and mobile objects between the camera and the truck that may not allow the necessary analysis to be performed correctly from just a picture snapshot. This setup ensures that the high-resolution video required for accurate license plate recognition is processed efficiently. Furthermore, this kind of resolution allows for not only analyzing license plate numbers but also supports the analysis of other important aspects such as driver facial recognition, shipping container numbers, seals, and even damaged areas. After the license plate is successfully read, the system deallocates the GPU container and terminates the 4K stream and network slice, thus optimizing resource utilization.

The flexibility of our approach allows it to be adapted for other applications, such as identifying marine container IDs or recognizing hazard symbols, demonstrating its versatility and potential for broader ITS applications. By leveraging the unique capabilities of 5G and containerization, our system offers a scalable, efficient, and cost-effective solution for real-time high-resolution computer vision tasks.

2. Materials and Methods

For the detection of a truck, we use YOLOV5 [3], a real-time object detection system. For the license plate recognition, we use EasyOCR [4], an Optical Character Recognition model. These algorithms are both containerized and deployed in a Kubernetes Cluster. The node where the Cluster is deployed is equipped with a GPU, whose resources are only accessed during the license plate analysis.

To handle the orchestration of the containers, an external component was created to manage them according to the events received (detection of a truck and analysis of a license plate) and trigger the changes in the Network Slice. The experimental evaluation of our approach utilizes a Huawei 5G SA Rel. 16 network, complemented by a custom-built slice manager designed to empower the 5G connectivity with fully dynamic slicing capabilities [5]. This slice manager oversees the provisioning and configuration of a low-quality slice to stream the 360p video for the detection of the truck then a high-quality slice to stream the 4K video for the license plate recognition.

3. Main Results

To evaluate the performance of our real time adaptive resource management solution, we conducted a set of tests, aimed at validating and quantifying the power consumption efficiency and the overall performance. We evaluated the solution by testing various scenarios both with GPU acceleration and without it, as well as by triggering changes in both networking and computing frameworks while maintaining the same service capability and improving efficiency.

The solution implemented proved to be considerably more resource and energy efficient considering both computational and radio resources, when compared to state-of-the-art non adaptive 5G based object detection systems [4], [6]. By dynamically adjusting the quality of the captured video stream and the network slice, the solution conserves bandwidth, allowing high bandwidth consumption only for the 4K video transmission needed to analyze the license plate. Additionally, the solution reduces power consumption by limiting GPU usage to the analysis of the license plate, while allowing the CPU to manage solely the truck detection phase.

Despite the resource saving techniques employed, the performance of the solution remains high. Even though the detection phase does not leverage the GPU resources, the detection time is efficient due to the low quality of the video stream, which can be handled only by the CPU in a reasonable time while allowing it to accurately detect the presence of a truck. The license plate recognition is also efficient, since the 4K video can be analyzed quickly when taking advantage of GPU resources. This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4. Conclusions

This paper presents a dynamic and efficient system for real-time high-resolution computer vision applications, leveraging the advanced capabilities of 5G technology and containerization. By initially utilizing a low-quality video stream for preliminary object detection and subsequently instantiating GPU-accelerated containers and 4K video streams upon truck detection, the system optimizes both computational and network resources. This approach not only ensures high accuracy and low latency in license plate recognition but also significantly reduces operational costs by dynamically allocating resources based on demand.

The flexibility and scalability of the proposed system demonstrate its potential to be adapted for various other applications, such as detecting marine container IDs or hazard symbols. The integration of 5G dynamic network slicing with containerized computer vision algorithms highlights a promising direction for the development of intelligent transportation systems and other real-time monitoring applications.

Future work could explore further optimizations, such as advanced predictive algorithms for resource allocation. Additionally, the system could be tested in a wider range of scenarios and environments to validate its robustness and adaptability.

Funding: This study was funded by the PRR – Plano de Recuperação e Resiliência and by the NextGenerationEU funds at University of Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project nº 53 with the application C645112083-00000059)

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Artificial Intelligence Advancements in Maritime Sustainability

Vala Ali Rohani [1,*], Tiago Pinho [1], Ana Mendes [1], Nelson Carriço [1], and Inês Abreu Ferreira [2]

[1] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal, vala.ali.rohani@ips.pt; tiago.pinho@esce.ips.pt; ana.mendes@esce.ips.pt; nelson.carrico@estbarreiro.ips.pt

[2] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; UNIDEMI - Research and Development Unit for Mechanical and Industrial Engineering, Instituto Superior de Engenharia de Lisboa, Polytechnic University of Lisbon; ines.ferreira@isel.pt

* Correspondence: vala.ali.rohani@ips.pt

Abstract: Adopting sustainable practices in maritime operations is essential for reducing greenhouse gas emissions, a critical factor in addressing global climate change. This article presents a systematic review of the applications of Artificial Intelligence (AI) in promoting maritime sustainability. A comprehensive search of the Web of Science database resulted in the retrieval of 127 relevant articles. These studies were analysed and categorised based on the specific maritime sector addressed, the type of AI algorithms employed, and their respective contributions to sustainability. The findings highlight the diverse applications of AI, from optimising shipping routes and enhancing fuel efficiency to reducing response times in smart ports and enabling real-time anomaly detection in dynamic maritime environments. By systematically categorising and evaluating these studies, this review provides valuable insights into AI-driven solutions' current state and potential in the maritime industry. The implications of this work are significant for researchers and practitioners, offering a consolidated knowledge base to inform future innovations and policies aimed at sustainable maritime operations. This article underscores the critical role of AI in advancing sustainability goals within the maritime sector, paving the way for more efficient, eco-friendly, and economically viable practices.

Keywords: maritime; sustainability; artificial intelligence; machine learning; data analytics

1. Introduction

Addressing global climate change necessitates the reduction of greenhouse gas emissions across various industries, including maritime operations. The maritime sector, a significant contributor to global emissions, is increasingly adopting sustainable practices to mitigate its environmental impact. This study explores the pivotal role of Artificial Intelligence (AI) in promoting these sustainable practices. This research categorizes and evaluates AI applications across different maritime sectors by systematically reviewing 127 articles from the Web of Science database. This review aims to offer a comprehensive understanding of the current state and potential of AI-driven solutions, providing valuable insights for researchers and practitioners committed to promoting sustainable maritime operations.

2. Materials and Methods

To systematically explore the applications of Artificial Intelligence (AI) in Maritime Sustainability, we employed a structured research methodology involving multiple data collection and analysis stages.

Initially, we queried the Web of Science (WoS) database using the search string: TS = "maritime" AND (TS = "sustainab*" OR TS = "carbon") AND (TS = "Generative AI" OR TS = Analytic* OR TS = "Machine Learning" OR TS = "Artificial Intelligence"). This query resulted in 209 articles. To ensure the relevance and impact of our sources, we sorted these articles by the number of citations and selected the top 50 most-cited articles for further review.

Recognising the importance of current research trends, we also selected all articles published in the last two years (2023–2024) from the initial query results, adding 69 more articles to our pool. We then combined these lists, resulting in a total pool of articles. A manual review was conducted to exclude any studies not directly related to our research focus, ensuring only the most relevant articles were retained.

For a more focused study, we identified articles with the keywords "Artificial Intelligence" and "Machine Learning" from the shortlisted pool, resulting in 15 highly relevant articles. These articles were then reviewed in detail and analysed from three perspectives, which are elaborated in the subsequent section of this article. This methodological approach ensured a comprehensive and targeted collection of relevant literature, providing a solid foundation for our research on the integration of AI and machine learning in enhancing maritime safety, security, and sustainability.

3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

These articles were reviewed in detail and analysed from three distinct viewpoints: "Maritime Sector," which focuses on various aspects of maritime activities and operations; "Applied Artificial Intelligence Use Case," which highlights specific AI and machine learning use cases in the maritime context; and "Contribution to Sustainability," which emphasises the role of AI and machine learning in promoting sustainability within the maritime sector. The details of these research results are provided in Table 1.

Table 1. Analysis of the contribution of Artificial Intelligence to Maritime Sustainability

Maritime Sector	Applied Artificial Intelligence Use case	Contribution to Sustainability
Smart Port & Maritime Activities	Predictive analytics and automated decision-making algorithms are employed in smart ports to automate and integrate end-to-end port operations, thereby reducing response time, improving asset utilisation, and enhancing logistics visibility. [1]	Contributing to sustainable maritime logistics by minimising environmental impact through efficient resource management and operational optimisation.
	Artificial Neural Networks are used to develop a port management system that accurately forecasts ship stay durations and potential delays, outperforming alternative approaches in terms of RMSE, MAE, and R2 values for both	Improves accuracy in forecasting ship stays and delays, leading to more efficient port activity planning and management, thus reducing operational expenses and environmental impact.

Maritime Sector	Applied Artificial Intelligence Use case	Contribution to Sustainability
	turnaround time and waiting period models. [2]	
	The DMLBC method explicitly employs machine learning algorithms integrated with blockchain technology to enhance efficiency in document control, traceability, loading processes, and collaborative workflows across seaports, addressing UN mandates for a Maritime Single Window and improving decision-making in port operations. [3]	Enhances efficiency and security in port operations, which supports sustainable practices; improves transparency and traceability in port logistics for better environmental practices; and enables advanced decision support and security measures for future port sustainability.
	The framework for Maritime Wireless Communications (MWC) integrates edge computing and machine learning models like LSTM and IF for real-time anomaly detection and cybersecurity in dynamic maritime environments, ensuring proactive risk management and compliance with international standards. [4]	Enhances anomaly detection and risk management for secure and effective maritime communication; Reduces latency and supports real-time communication and safety measures in maritime operations.
	Utilising big data and artificial intelligence to enhance maritime safety and security by transforming data from seas and maritime activities into actionable insights for surveillance systems is crucial for protecting sensitive sea areas and coastal facilities. [5]	Enhances maritime safety and security by developing AI-driven surveillance systems, ensuring sustainable operations in sensitive sea areas and critical coastal facilities.
Navigation & Routing	Predictive analytics and route optimisation algorithms are used in maritime to guide cargo ships to safe routes and avoid danger zones. [6]	Enhancing maritime safety by leveraging machine learning to guide ships in real-time, optimising routes to avoid danger zones and reduce potential risks, thereby promoting safer and more sustainable maritime operations.
	Applying an enhanced DBSCAN clustering algorithm with the Mahalanobis distance metric to AIS data for modelling vessel behaviours and detecting trajectory anomalies such as unexpected stops, route deviations, and inconsistent speeds. [7]	Supporting sustainable development by ensuring efficient and safe marine transportation operations by modelling vessel behaviours, enabling detection of anomalies and enhancing safety measures.
Vessels	Developing predictive models for condition-based maintenance of naval propulsion systems, specifically gas turbines, to diagnose and forecast	Enhancing naval propulsion reliability and sustainability by advancing to condition-based maintenance, reducing downtime, optimising scheduling, improving

Maritime Sector	Applied Artificial Intelligence Use case	Contribution to Sustainability
	equipment degradation and potential failures [8]	efficiency, and lowering environmental impact.
	Artificial Neural Networks are employed to predict harbour vessel emissions, demonstrating better accuracy than traditional methods like the bottom-up approach. [9]	Enhancing emissions prediction accuracy by up to 48% for nitrogen oxides and 62% for carbon monoxide, aiding in monitoring and reducing environmental impact.
	Employs Multi-Layer Perceptron (MLP) and Radial Basis Function (RBF) neural networks to estimate NOx and CO2 emissions from in-cylinder pressure data of a maritime diesel engine, highlighting MLP's superior accuracy over RBF. [10]	Accurate estimation of NOx and CO2 emissions using ANN helps in monitoring and reducing emissions, contributing to cleaner maritime operations.
	Machine learning models, including K Nearest Neighbour Regression and Light Gradient Boosted Machine Regression, achieve 84% and 81% prediction accuracy, respectively, in estimating CO2 emissions from ship voyage data, facilitating decision-making for optimising ship operations under emissions reduction goals set by the International Maritime Organization. [11]	Helps in decision-making to optimize ship operations, reducing CO2 emissions and contributing to the goal of a 50% reduction in maritime gas emissions by 2050.
Energy & Fuel	Machine learning techniques such as predictive modelling and optimisation algorithms are employed to analyse data from voyage planning systems, weather routing algorithms, and operational parameters (like torque limitations) to maximise energy efficiency in maritime operations. [12]	Enhancing energy efficiency in maritime operations through behavioural change and operational optimisation, leveraging data-driven decision-making and technological solutions to achieve significant fuel savings.
	Artificial Neural Networks are used to develop a novel method for predicting fuel consumption and carbon emissions based on onboard measurement data from smart ships, achieving high accuracy rates of 81.5% in diesel mode and 91.2% in gas mode. [13]	Enhances understanding of factors influencing fuel consumption for better emission reduction; Improves fuel efficiency and reduces carbon emissions through better prediction methods.
	The CatBoost algorithm was utilised to predict ship fuel costs with an R2 value of 0.976, showing superior performance over other methods. It identifies key variables such as distance, sea days, speed, duration, and port days that significantly influence predictions, aiding PCTC companies' inefficient fuel	Enhances fuel cost predictions for better operational efficiency and environmental compliance; identifies key variables affecting fuel costs, aiding in cost reduction and emission control, contributing to sustainable shipping practices.

Maritime Sector	Applied Artificial Intelligence Use case	Contribution to Sustainability
	cost estimation and enhancing sustainability in maritime logistics. [14]	
	This study integrates speed and trims optimisation to reduce fuel consumption in maritime operations, achieving significant savings of 12.30% and 11.70% (before and after smoothing) in ballast conditions and 10.18% and 9.47% under full load conditions, surpassing single-parameter optimisation approaches. [15]	Demonstrates significant fuel savings through joint optimisation of speed and trim, enhancing fuel efficiency and reducing emissions.

4. Conclusions

This systematic review highlights the transformative potential of Artificial Intelligence (AI) in promoting sustainability within the maritime sector. By categorising and analysing 127 relevant articles, we have identified key areas where AI can significantly impact maritime operations. The findings reveal that AI applications in the maritime industry are diverse, from optimising shipping routes and enhancing fuel efficiency to reducing response times in smart ports and enabling real-time anomaly detection. These advancements not only improve operational efficiency but also contribute to the reduction of greenhouse gas emissions, aligning with global sustainability goals.

The implications of this study are substantial for both researchers and practitioners. For researchers, this review provides a comprehensive knowledge base that can guide future studies and innovations in AI-driven maritime sustainability. For practitioners, the insights gained from this analysis can inform the development and implementation of AI technologies to achieve more eco-friendly and economically viable maritime operations. Ultimately, the integration of AI into the maritime sector represents a critical step towards achieving sustainable development and mitigating the environmental impact of maritime activities.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n. º 53)

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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NEXUS: A 5G Strategic Vision for Sines' Port of the Future

Francisco Fontes [1], João Bastos [1], André Coelho [2] and Manuel Ricardo [2]

[1] Altice Labs, S.A.; fontes@alticelabs.com; bastos@alticelabs.com
[2] INESC TEC, Faculdade de Engenharia, Universidade do Porto; andre.f.coelho@inesctec.pt; manuel.ricardo@inesctec.pt

Abstract: International seaports play a key role in trade, logistics, and in the global supply chain. Within this context and to enhance operational efficiency and minimize costs, there is a growing interest in integrating advanced technological solutions in seaports, including novel video surveillance, cargo handling, and mission-critical communications solutions. This will allow for environment-aware and data-driven aided decisions as well as adaptive management of the seaport operations in real-time. For that purpose, a reliable, secure and high-capacity wireless communications solution for seaport ecosystems is of paramount importance for this technological evolution.This paper presents a 5G strategic vision for Sines' port of the future. This vision includes a 5G services platform designed to address the heterogeneous requirements related to key use cases, including communications for public protection and disaster relief (PPDR), video analytics for mobility and surveillance, and cargo handling.

Keywords: 5G network; 5G Services Platform; 5G Use Cases; Port of the Future; Standalone Non-Public Network.

1. Introduction

The path to the seaport of the future - scalable, resilient, and adapted to the demanding requirements of maritime transport - goes through the integration of new information and communications technologies in its processes. In this context, recently released mobile communications technologies, namely 5G [1], act as a catalyst and a determining factor in the digital transformation and transition process of the transport and logistics industry.

Digitalization of port logistics operations, increased process automation, and improved automation of multichannel supply chains demand faster and more efficient communications, with very high levels of availability and scalability. In this context, the introduction of the fifth generation of mobile communications technologies in the port environment aims to enhance the growth and effectiveness of operations and, at the same time, improve carbon efficiency per unit of cargo handled, by reducing shipping loading and unloading operation time.

Within the scope of the NEXUS project, the Work Package 6 – 5G Connected Port – aims to study and develop an innovative solution to provide low latency, high-density and bandwidth business mobile services to the port and logistics community of Sines. The choice of the final architecture of the solution to be implemented follows an evolutionary approach, based on critical technical and business aspects for determining the optimal technological solution, considering the expected evolution of the port business and the supporting information and communications technologies.

The 5G service platform for the Sines' port of the future must respond in an agile and environ-mentally sustainable way to the business requirements of different stakeholders while considering economic and regulatory constraints, such as Operational

Expenditure (OPEX), Capital Expenditure (CAPEX), and legal and operational policies. Adequate 5G monetisation and business models should consider these elements and, most importantly, the relevance of directionality and strategy of technology and innovation development for potential end users.

This poster presents the NEXUS 5G Strategic Vision for Sines' Port of the Future, including a 5G services platform that takes advantage of 5G technology to address the heterogeneous requirements associated with key use cases, identified hereafter.

2. 5G Services Platform

The Port of Sines 5G services' platform was designed taking in consideration the level of technological maturity of existing solutions and standardization roadmaps. Technical and functional requirements were derived from the analysis of an initial set of use cases defined for the project, including communications for public protection and disaster relief (PPDR), video analytics for mobility and surveillance, and cargo handling.

The technical approach to Port of Sines 5G network and services platform design encompasses two main phases: the first phase involves the deployment of a 5G Standalone Non-Public Network (SNPN) in the containers terminal (Terminal XXI), built around a standalone 5G core, a radio access network (RAN), and a set of radio units (RU), covering key points of the terminal. This network will allow to validate the suitability of the technology for this specific use and to identify the main technical requirements for the final network architecture design. The second phase of the design will focus on the definition of the technical and economic guidelines that will allow the Port of Sines Authority to choose for the best approach to follow to provide the Port of Sines community with a common 5G services' platform.

Considering the dynamic and highly demanding environment of a seaport, especially in emergency situations, the extension of 5G network coverage to remote areas for well-defined periods and situations is crucial. Hence, the existence of a 5G mobile cell is of paramount importance, since it will allow to extend the coverage of the 5G network, either a Public Land Mobile Network (PLMN) or a Non-Public Network (NPN) or reinforce existing ones to areas beyond the reach of fixed 5G infrastructure. Studies were carried out towards the development and implementation of a Mobile Cell as a nomadic node, which can be transported, for example, on land vehicles or tow boats.

Equally important is the understanding of the strategies of different entities operating in the Port of Sines' ecosystem regarding their information systems, communications networks (fixed and mobile), and innovation. This will enable the exploration and adoption of new technological solutions and the viability of the associated economic models. To assess feasibility, a survey has been carried out to gather the organizations' perspectives and concerns for mobilizing the 5G network and services' adoption. The results of this survey were then used to determine the private 5G mobile network model that is best suited to serve port's community. Conclusions will be presented in a NEXUS WP6 workshop that will take place in January 2025.

3. 5G-enabled Key Use Cases

In a constantly evolving digital society, mobile devices demand communications anytime, anywhere. In port scenarios this is no exception. Ports, as critical hubs for global trade, may experience a constant succession of activities. Ships docking and departing, containers being loaded and unloaded, and a multitude of logistics and administrative tasks, centrally managed and taking place in real-time, require high-capacity and ultra-reliable communications.

However, unique challenges are imposed to the RANs in these scenarios. Ports can experience temporary events, such as the arrival of a large fleet of ships or emergency management situations, leading to network congestion and network failures. This can be due either to obstacles affecting radio signal propagation or even by radio interference from ships' RADAR, which may degrade the performance of existing wireless networks operating in unlicenced frequency bands (e.g. Wi-Fi networks). These dynamic conditions motivate the use of reconfigurable wireless network solutions.

On-demand networks, with their flexibility regarding reconfiguration and positioning capabilities, have emerged as a suitable solution to address these challenges. Specifically, an on-demand 5G network can improve the QoS offered and promote enhanced security when deployed as a private network. These are aspects typically required by entities operating within port environments. Three use cases were identified in NEXUS WP6 that were considered to deserve special attention.

3.1. Video analytics for mobility and surveillance

In the context of seaport activities, video analytics service is particularly important since it can provide environmental awareness over port's operations, but it can also improve risk evaluation, enhancing the performance of decision-making processes. For areas such as terminal berths, storage yards, gates, roads, and inspection zones, the installation of a video surveillance system can facilitate real-time monitoring of different elements, including quay cranes, yard bridges, people, vehicles, containers, and port boundaries.

While many ports rely on optical fibre network solutions for data transmission, specific areas without a fixed communications infrastructure may take advantage of the 5G wireless connectivity to enable reliable and ubiquitous communications. Being a type of infrastructure where the space geometry is often changed, high quality and secure video surveillance solutions supported on a mobile 5G network can significantly improve the port's services' infrastructure. The 5G network offers the potential for improved flexibility, while allowing to meet dynamic network requirements. This will improve the identification and management of different risk events at the port, potentially resulting in more efficient operations.

Moreover, unmanned aerial vehicles (UAVs) equipped with on-board video cameras, remotely controlled via the 5G network, allow for enhanced mobile surveillance capabilities. UAVs can provide real-time video data, complementing the capabilities of ground-based surveillance systems.

3.2. Cargo handling

In traditional seaport environments, except for quay cranes that have optical fibre connectivity, mobile cranes and other machinery typically either lack communications systems entirely or primarily rely on Wi-Fi networks for remotely controlled operation assistance [2]. However, the dependence on Wi-Fi introduces multiple challenges, such as:

- Communications disruptions caused by multiple sources of interference, including ship RADARs operating at frequency bands adjacent to those used by Wi-Fi;
- Limited support for seamless connectivity, which can increase the packet loss ratio when the remotely controlled mobile cranes or other machinery moves;
- Insufficient capacity to meet strict network requirements of remotely controlled machinery, especially ultra-reliable and low latency communications;
- Increased cost for deploying and maintaining several Wi-Fi Access Points (APs), which are used to ensure wireless connectivity.

5G technology offers a solution for enhanced Mobile Broadband (eMBB) and ultra-reliable low latency communications (URLLC) [2]. By equipping each mobile crane with a 5G Customer Premises Equipment, this will allow ensuring a wireless connection to a centralized controller via the 5G RAN. Additionally, the remote controller system can optimize processes such as cargo management, route planning, and cargo ship scheduling by leveraging the data received from the mobile cranes through the 5G network.

3.3. Mission Critical Communications for public protection and disaster relief (PPDR)

Reliable communications' infrastructures play a critical role in enabling port operations. Traditional port communication networks typically provide narrowband services for voice communications and text messaging. Nevertheless, as port operations become more complex, these networks typically hinder exchanging large amounts of data and high-definition video, required by novel applications and services.

To mitigate these issues, ports have been leveraging Commercial-Off-The-Shelf (COTS) mobile radio terminals for broadband communications. However, implementing proprietary communications infrastructures exhibits challenges regarding cost, scalability, and interoperability.

A promising solution is the usage of cellular networks. Within this context, 3GPP, a partnership project that brings together national standards development organizations from around the globe, has introduced in Release 12 features for mission-critical communications, such as Push-To-Talk (PTT). Initially integrated into 4G networks, these capabilities were improved in subsequent releases, including 5G, to enable video and data transmission capabilities.

The usage of mission-critical communications in 5G networks can potentially enhance efficiency in different tasks, including seaport's operations, while offering the ability to share live video streams and data in real-time [3, 4]. This feature is especially relevant to seaport operations, where visual data can improve decision-making, safety, and efficiency. A good example of its applicability could be found during emergency or disaster situations, where the (almost) instant access to location, biometric or environmental information of operational personnel on the ground is of utmost importance and where high-quality video communications could dramatically improve the quality of the assistance provided.

4. Conclusions

Seaports, which assume a key role in international trade and economic growth, are leveraging the potential of 5G technology to improve their efficiency. Given the myriad nature of seaports and the different devices, vehicles, and machinery used, a reliable and high-capacity network is of paramount importance. 5G networks hold the potential to meet orthogonal requirements using the same physical network infrastructure, including:

- Reliability and availability, ensuring continuous operations without communications disruptions;
- Flexibility, enabling adaptability to seaport expansion and system improvements over time;
- Mobility, providing reliable wireless coverage to multiple devices, anywhere, anytime;
- Scalability, regarding both hardware and software components, to accommodate future improvements and novel functionalities of the network;
- Security, ensuring protection against cyber threats, while allowing data privacy, especially when deployed as a non-public network.

When it comes to taking advantage of 5G in seaports, a use case envisioned is the integration of 5G-enabled video cameras to monitor seaport activities in real-time. By leveraging video analytics, video cameras can track vehicles and machinery, while potentially improving operations and enabling the exchange of large amounts of data. Moreover, as port environments typically face challenges associated with the limited space and the continuous growth in trade volume, the need for innovative cargo handling solutions becomes paramount. Within this context, the enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low-Latency Communications (URLLC) are enablers for transforming traditional ports into smart ports. Another relevant application in seaports communities is the 5G Mission Critical Push to Talk (MCPTT), where 5G offers real-time, group communications, with the possibility of exchanging voice and data, which are essential in seaports' daily activities for enhanced situational awareness and people coordination.

The 5G Core network to be deployed in Sines will be flexible, capable of accommodating multiple access technologies including those already in place, providing adequate QoS. On-demand networks, known for their flexibility regarding reconfiguration and positioning capabilities, are also a promising solution for providing wireless connectivity in dynamic scenarios; in Sines, this will be leveraged by a Mobile Cell which can significantly improve the connectivity in select locations and enhance the QoS offered to selected users and machinery, especially when deployed as a non-public network.

As future work, 5G services platform will be further evolved and a framework for business, operation, and management scenarios will be established.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n. º 53)

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The legal framework of digitalization and decarbonization of ports

Marcelly Fuzaro Gullo [1], Stéfani Reimann Patz [1] and Carla Barbosa [1]

[1] University of Coimbra, Portugal; marcellymfg@hotmail.com; stefani.patz@hotmail.com; cbarbosa@fd.uc.pt

Abstract: In the digital age, ports are adopting smart technologies such as IoT and AI to improve efficiency, reduce costs, and become more sustainable. (1) This article explores the legal framework of digitalization and decarbonization in the port sector. (2) The methodology includes a deductive and analytical approach to highlight relevant aspects of each topic. (3) It demonstrates how digitalization and decarbonization aligns with international and European legal instruments and reveals some legal-ethical challenges arising from digitalization (4) In conclusion, the transition of traditional ports into green and smart ports is a comprehensive approach to achieving sustainability, modernization and resilience in the maritime industry. By integrating advanced technologies, ports can significantly reduce their carbon footprint and contribute to global environmental goals. Alignment with international and European standards ensures that these efforts are consistent and impactful.

Keywords: Ports, Green Ports, Smart Ports, Digitalization, Decarbonization, Resilience, Legal challenges.

1. Introduction

Since the advent of cross-border maritime transport, ports have played a fundamental role in international trade. Currently, more than 80% of goods, by volume, are transported by maritime routes [1]. Ports are of great economic and strategic importance, contributing to local and regional development and economic growth. Consequently, they attract constant attention and debate from stakeholders in both the public and private sectors involved in and affected by their activities.

According to studies on challenges handled by ports and its infrastructures on global level, carried by the International Association of Ports and Harbors – IAPH, in 2022, the maritime sector faces relevant gaps in terms of "efficiency, connectivity and accessibility, digitalization, decarbonization, shipping costs and regulatory environment", demanding "key actions" in digitalization, decarbonization and resilience for the maritime sector [2] (p. 9).

Ports need to be prepared and resilient to deal with crises and manage instabilities that may affect international trade, such as geopolitical tensions, environmental pressures, or health and humanitarian crises. For example, during the COVID-19 pandemic, the global supply chain felt the impact of sudden changes in demand patterns, revealing that most ports were not prepared in terms of capacity and efficiency for abrupt changes in their operations [3] (p. 11).

The pandemic crisis accelerated the digitalization of ports and their infrastructures, highlighting the need for greater flexibility and better capacity to respond to changing scenarios. Ports that had not yet started the digital transition were forced by circumstances to accelerate their process and adaptation. Measures implemented, as established in the Trade Facilitation Agreement - TFA of the World Trade Organization -

WTO, included promoting transparency, simplifying and automating procedures, using computerized systems and electronic documentation, harmonizing customs requirements, and strengthening border cooperation [4]. These initiatives aim to decrease both the time and costs associated with trade transactions.

At the same time, this transition, although necessary, brings legal challenges that must be considered and addressed by ports in order to minimize the associated risks, such as issues of data protection and misuse of personal data, violation of employees' rights, cybersecurity and liability, infringement of intellectual property, and others.

2. Methods

Regarding the methodology employed, a deductive approach combined with analytical methodology was adopted, conducted through indirect research by consulting books and scientific journals. The study's proposal is to situate readers about some legal relevant aspects and challenges of each topic that assist in the overall understanding of the proposed inquiry.

3. Main results

3.1 Digitalization Framework – Smart Ports

The creation of an efficient digital ecosystem is crucial for streamlining operations and facilitating data exchange between shipping lines, port services, cargo handling operations, clearance agencies, and other transport networks. According to Gyu Serb Kim, the five essential requirements for port digitalization are: cooperation and collaboration between ports, including data sharing and benchmarking good practices; investment in exclusive and specialized networks such as the 5G network; continuous communication with the tech industry to keep up with trends; ensuring stakeholder consensus, including conflict management; and a long-term strategy coordinated by a top leader [5].

Smart Ports use advanced technologies to digitally transform key business processes, enhance security, improve operational efficiency, and promote sustainability. Port digitalization, or Port 4.0, involves applying Industry 4.0 tools and concepts to modernize and increase the handling capacity and productivity of port operations and processes, meeting the growing demands of global trade [6].

The legal framework for the digitalization of the European port sector is structured by key regulations and strategic initiatives that aims to ensure the efficiency, security, and sustainability of European ports. For example, the Regulation (EU) 2019/1239, known as the European Maritime Single Window Environment Regulation, streamlines and digitalizes administrative processes in ports.

3.2 Decarbonization Framework of Ports – Green Ports

Ports play a crucial role in decarbonizing the maritime sector. Greenhouse gas (GHG) emissions from maritime transport totaled 1.076 million tonnes in 2018, a 9.6% increase from 2012. Of these emissions, CO_2 accounted for 1.056 million tonnes in 2018, a 9.3% increase from 2012 [7] (p. 1). In response, the International Maritime Organization (IMO) developed instruments to address CO_2 emissions, including the 2023 IMO Strategy on Reduction of GHG Emissions from Ships [8], supporting the UN Sustainable Development Goal 13 to combat climate change [9]. These efforts align with the 2015 Paris Agreement, which aims to keep the global temperature rise well below 2 degrees Celsius above pre-industrial levels, while pursuing efforts to limit the increase to 1.5 degrees Celsius [10].

The legal framework for decarbonization in the European port sector is comprised of essential regulations and strategies. For example, the Regulation (EU) 2015/757 (MRV) establishes standards for monitoring and reporting CO2 emissions from ships; the Directive 2014/94/EU mandates the creation of infrastructure for clean fuels in ports; the Regulation (EU) 2021/1119 (European Climate Law) sets targets to achieve climate neutrality by 2050; the European Green Deal and the Sustainable and Smart Mobility Strategy promote emission reductions in the transport sector. Additionally, the European Regulation for the Trans-European Transport Network (TEN-T) supports the development of a comprehensive and sustainable transport network across Europe. These measures aim to ensure sustainability and carbon reduction in European ports.

3.3 Port of Sines and the NEXUS Agenda – Portuguese Recovery and Resilience Plan

The Port of Sines, located on Portugal's Atlantic coast, is a crucial logistics hub for international trade. It leads the NEXUS Agenda consortium, which brings together 35 partners committed to developing innovative solutions to promote green and digital transitions. This initiative seeks to explore new technologies and sustainable practices to improve operational efficiency, reduce environmental impact, and position the port as a leader in the green and digital economy [11] [12].

Transforming the Port of Sines into a Green and Smart Port represents significant modernization and innovation in the Portuguese port sector. The benefits extend to the entire port community, enhancing competitiveness in the global market and contributing to sustainable development and economic growth in the region.

Inserted in the Portuguese Recovery and Resilience Plan - PRR, the NEXUS Agenda contributes to resilience by implementing innovative solutions that strengthen the economic and social structures of Portugal, investing in essential areas such as infrastructure and transportation.

3.4 Legal challenges

Digitalization and automation in the port sector face several legal challenges, primarily due to the complexity and innovative nature of the technologies involved. The lack of specific regulation for new technologies, such as cyber-physical systems, the Internet of Things (IoT), and big data, creates a legal uncertainty environment. This regulatory gap can lead to difficulties in ensuring compliance with existing standards and an increased risk of legal liabilities. Companies adopting these technologies must navigate a variety of regulations in different jurisdictions, which can result in conflicts of laws and additional implementation challenges [13]. Furthermore, the need for data protection and privacy is exacerbated by the vast amount of information generated and processed by these technologies, increasing the complexity of ensuring compliance with legislation such as the European Union's General Data Protection Regulation (GDPR) and the EU Artificial Intelligence Act (AI Act).

Another significant challenge is the management of risks associated with cybersecurity. The integration of cyber-physical systems and the interconnectivity provided by IoT increase vulnerability to cyber-attacks, requiring ports to adopt robust security measures to protect critical infrastructures and sensitive data. The rapid evolution of cyber threats necessitates a dynamic and adaptable legal framework that can keep pace with technological innovations and new attack methods [14]. Additionally, automation and digitalization raise questions about legal liability in the event of operational failures or incidents, necessitating clarifications regarding the civil and criminal liability of companies and their managers. These issues underscore the need for international cooperation to develop standards and guidelines that can provide a solid and harmonized legal foundation to support safe and efficient digitalization in the European port sector.

4. Conclusions

The transition from traditional ports to Green and Smart Ports represents a comprehensive and strategic approach to achieving sustainability in the maritime industry. This transformation involves integrating advanced technologies, enabling ports to operate more efficiently and reduce operational costs. Besides efficiency and cost savings, these technologies significantly reduce carbon footprints, contributing to global environmental goals and combating climate change. Green and Smart Ports align with European and international standards and regulations.

Future research should focus on the long-term impacts of port digitalization on global trade and the environment. Additionally, exploring challenges and solutions for implementing these technologies across diverse port infrastructures, considering regional and contextual differences, is necessary. Data management and privacy must also be prioritized, ensuring transparency and accountability in data protection while maximizing the benefits of digitalization. In summary, the framework of digitalization and decarbonization in ports offers an opportunity to revolutionize the maritime industry, making it more sustainable, digital, and resilient.

Funding: Content produced within the scope of the NEXUS Agenda - Innovation Pact – Green and Digital Transition for Transport, Logistics and Mobility, financed by the PRR.

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Benchmarking Performance Indicators: A Conceptual Report Toward a Multi-Scalar Approach to Port Performance

Bárbara Fontainha [1,*], António Santos [2], Ana Mendes [3], Marcela Castro [3] and Tiago Pinho [3]

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal, barbara.fontainha@ips.pt
[2] Administração dos Portos de Sines e do Algarve, SA-Sines, Apartado 16, 7521-953 Sines, Portugal; antonio.santos@portodesines.com
[3] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, 2910-761 Setúbal, Portugal; ana.mendes@esce.ips.pt; marcela.castro@esce.ips.pt; tiago.pinho@esce.ips.pt
* Correspondence: barbara.fontainha@ips.pt

Abstract: Globalization, increased connectivity of transport networks, and progress in land connections highlight the strategic role of seaports in global trade and supply chains. However, port management faces challenges related to operational efficiency, sustainability, and competitiveness. This study aims to propose a multidimensional approach to Key Performance Indicators (KPI) to assess port efficiency, encompassing KPI from the foreland, port operations, and hinterland dimensions. The methodology includes a literature review on KPI in the seaport sector, focusing on the interrelationships between the operational and institutional dimensions. The main results include the development of a conceptual framework that integrates institutional and operational indicators, promoting a comprehensive assessment of port efficiency. Unlike previous approaches focused on isolated aspects, this model incorporates multiple dimensions that influence the overall competitive performance of ports. It is concluded that the proposed conceptual framework offers a resilient and adaptable basis for port assessment, contributing to the identification of inefficiencies and alignment with emerging environmental regulations, and serving as a guide for continuous improvement and global competitiveness.

Keywords: Key Performance Indicators; Maritime Port; Seaport; Conceptual Framework; Port Performance; Port Foreland KPI; Port Hinterland KPI.

1. Introduction

The current scenario presents a globalized economy, increased connections to global transport networks, changes in inter-port relations, and progress in improving land port connections. In this context, the maritime port sector is gaining prominence in world trade and maintaining the global supply network. Ports function as connection points between global distribution networks and conduct their operations in a market environment that is geared towards efficiency, competitiveness, and constant change [1]. As a result, there has been an unprecedented increase in demand for port services in the industry, raising the strategic importance of seaports for the sustainability of the world economy.

The observed expansion can be rationalized by the considerable economic impact that seaports have on the international market and their role in facilitating and transporting around 80% of global trade in goods through maritime channels [2]. However, despite this progress, according to Laxe *et al.* [3] port management has been faced with challenges related to the sustainability of operational practices, along with the search for cost efficiency and quality in the provision of services to maintain competitiveness on a global scale.

This scenario reinforces that changes in the maritime sector have called for strategies that integrate multiple sides of maritime activities [4] considering the perspectives of different stakeholders in ports [5], without forgetting that ports face increasing demands to align their performance with sustainability requirements [4], especially with the application of existing regulations aimed at reducing CO_2 emissions in international maritime operations by at least 50% by 2050 [6].

The reality is that port managers are increasingly faced with the task of formulating port strategies that strike a balance between the interests of all stakeholders [1] and that will result in increased operational efficiency, guarantee of high levels of service and respond to the interests of stakeholders. For Laxe *et al.* [3] as a response to these challenges, it is necessary to maximize the optimization of their functions in direct response to the needs arising from the sector's current economic and spatial dynamics.

In this sense, Rijkure [7] points out that the evaluation of port efficiency helps in the validation of up-to-date strategic development principles, the evaluation of operational efficiency, the achievement of goals, and the elaboration of strategies for the long-term growth of ports, while van de Ven *et al.* [8] reinforces that organizations must evaluate their operations and frameworks to verify the extent to which their objectives are being achieved.

For Domínguez *et al.* [9] one viable way to carry out this evaluation is to measure the performance of organizations based on metrics known as Key Performance Indicators (KPI). Badawy *et al.* [10] indicates that KPI make it possible to gather knowledge and explore the best way to achieve the organization's objectives and play a vital role in helping organizations achieve excellence[1].

KPI encompasses a range of metrics that focus on the key areas of organizational performance that have the greatest importance for the organization's present and future achievements [9] and which reflects the state/progress of the company [11]. Finally, it allows to further compare the strengths and weaknesses of different container ports at the terminal level, port level, and region level [12]. Against this backdrop, developing a comprehensive approach to port performance assessment is a key challenge, as ports serve multiple stakeholders and are influenced by numerous factors [13].

This study seeks to identify the most relevant KPI and consolidate them into performance dimensions in the maritime port industry. The aim is to introduce a management vision based on multidimensional port efficiency, considering, for example, social KPI, which are little explored in academic research on maritime transportation, but essential for assessing the overall performance of ports in a competitive sector [14]. In addition, the aim is to identify how these indicators influence strategic decision-making and increase management effectiveness [15]

The research will cover the following sections: first, the definition and literature review on the scope of each dimension (Maritime, Terminal, Hinterland) will be presented; second, the academic results on the most relevant indicators identified will be presented. Third, the research methodology for selecting the most relevant academic results will be presented. Subsequently, the main indicators identified will be disseminated through a multidimensional framework for assessing the port's performance, since the main results of each dimension tend to be different [16]. Fifth, the research questions will be discussed, followed by the conclusions and contributions.

2. Materials and Methods

To answer the starting question, a literature review will be carried out to identify studies on KPI in the port maritime sector that are currently most used, encompassing maritime, terminals, and hinterland, considering that these dimensions are interrelated and that inefficiencies in one dimension are most likely to affect the others [1]. This general framework aims to promote the monitoring of the main indicators currently identified in each dimension of the continuous cycle of maritime port operations and to make the future development of strategic initiatives comprehensively responsible.

For the basis of the research, we will consider studies and reports published in the maritime and port area focused on KPI over the last 5 years (2019-2024).

The online search incorporated and combined important keywords, including Key Performance Indicators, Maritime Port, Seaport, Conceptual Framework, and Port Performance among the main scientific databases (Scopus, Web of Science).

- "Scopus" search including title, abstract, and keywords;
- "Web of Science" search including keywords;
- Bibliographic research in books (e.g. " Port Economics Management and Policy").

3. Results

This study proposes a model for measuring port performance through a conceptual framework of KPI that works in layers, each representing a critical dimension of port performance. This system allows port managers to assess performance in both an isolated and integrated way, promoting flexible adaptation to the different contexts and demands of the sector. As mentioned by Duru et al[13], the model broadens the understanding of ports as complex commercial entities and highlights the interconnection between dimensions, where inefficiencies in one area affect overall performance [1].

In short, the proposed model will guide managers in adapting to constant regulatory changes and global demands and offer an adaptable framework for continuous and integrated analysis in the port sector. In short, the combination of these three dimensions allows for detailed analysis, while offering a systemic view that will help identify specific inefficiencies in one dimension and align operations according to a continuous and integrated flow of operational performance, according to the model framework in Figure 1.

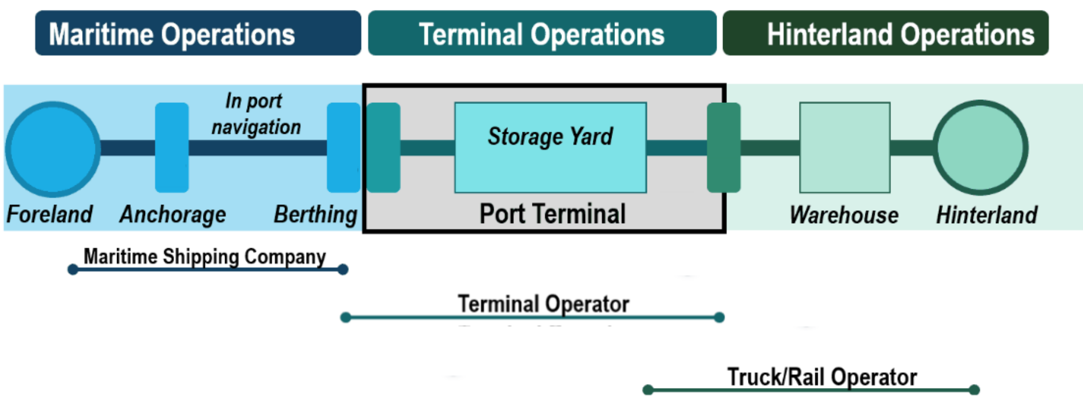

Figure 1. Multi-Scalar Port Performance Measurement Framework (Adapted [1])

4. Conclusions

This article proposes a conceptual framework for assessing port efficiency in a resilient and adaptable way to future changes in the sector. The proposed model aims to help ports identify inefficiencies and drive continuous improvements, promoting global competitiveness and alignment with emerging environmental regulations. This conceptual framework could serve as a basis for the development of integrated indicators that meet the operational and sustainability requirements of the port sector.

The article proposes a model for the future of port performance evaluation that recognizes the multidimensional nature of port performance, developing holistic and adaptable measurement methods capable of responding to new challenges. Unlike studies focused on isolated aspects, this approach addresses the various dimensions that influence port overall performance. The benchmarking proposed is, therefore, essential for optimizing operations and ensuring efficiency and sustainability.

In addition, the performance metrics analysis broadens the understanding of port management and proposes alternatives to current challenges. However, the approach must consider limitations such as cultural variations, local regulations, and specific stakeholder needs, which can affect the application of the model and generate unexpected results. A balanced perspective is therefore essential for a sustainable strategy in the sector.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53).

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Interactive Dashboards for KPIs Monitoring in Seaports: A Proof of Concept at the Port of Sines

Liandra Henriques [1,*], Diana Marques [2], António Rosa [3], Samuel Martins [4], Miguel Lopez [5], António Amaral [6], Ana de Jesus Mendes [7]

[1] Department of Information Systems Management, ISEG - Instituto Superior de Economia e Gestão , Lisbon University, 1200-781, Lisboa, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; l48671@aln.iseg.ulisboa.pt; liandra.henriques@esce.ips.pt;
[2] Department of Electrotechnical Engineering, ISEP – Instituto Superior de Engenharia do Porto, Polytechnic of Porto, 4200–072, Porto, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; 1181197@isep.ipp.pt; diana.marques@esce.ips.pt;
[3] Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal; 202100772@estudantes.ips.pt;
[4] APS - Administração dos Portos de Sines e Algarve, Sines, Portugal; samuel.martins@portodesines.pt
[5] Department of Informatics Engineering, DICE Lab – Centro ALGORITMI, Universidade do Minho, Guimarães, Portugal, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal; miguel.lopez@estsetubal.ips.pt
[6] INESC TEC - Institute for Systems and Computer Engineering, Technology and Science, 4200-465, Porto, Portugal, School of Engineering, Polytechnic Institute of Porto, 4249-015, Porto, Portugal; sal@isep.ipp.pt
[7] RESILIENCE – Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS – Estefanilha, 2910-761 Setúbal, Portugal; ana.mendes@esce.ips.pt
* Correspondence: liandra.henriques@esce.ips.pt

Abstract: In the maritime transport sector, effective and sustainable monitoring of Key Performance Indicators (KPI) is essential to optimize port operations and meet the growing demands of global trade. This research is dedicated to developing a proof-of-concept dashboard that integrates real-time KPI data from various sources. It involves an exploratory literature review, a market analysis of existing seaport dashboards, and consultations with industry experts to identify the main KPI. The study’s primary goal is to guide development and analyse relevant datasets that ensure data quality and integration. This innovative dashboard seeks to enhance stakeholder collaboration, optimize port management, and facilitate decision-making. Ultimately, it aims to improve operational efficiency and competitiveness within the maritime transport sector.

Keywords: Dashboard; KPI; Maritime Port; Seaport; Management; Performance.

1. Introduction

Currently, the maritime transportation sector faces significant demands from the global economy [1]. As a result, ports are under greater pressure to enhance their performance and address economic, environmental, energy, and operational challenges, impacting their sustainability [2].

In this context, effective monitoring and management of port performance are essential for ports to make effective and efficient choices, contributing to operational efficiency and environmental sustainability. To achieve this, we have studied and selected a group of Key Performance Indicators (KPI) to use as quantifiable metrics for assessing the organization's success in achieving its strategic objectives [3].

Interactive dashboards are crucial management tools to visually represent KPI and other relevant data to provide a quick overview of the organization's performance. By integrating these dashboards, seaport stakeholders can effectively monitor the port activities and measure their progress towards their goals [4].

This approach is used to foster and manage long-term growth and competitive advantage within the organization through people, systems, and procedures. Each perspective reveals a unique set of indicators that function as dashboards. These indicators provide critical knowledge factors that support the monitoring of business strategies and the design and schedule of organizational processes [5].

Visual data representation is an essential element of strategic decision-making in organizations [6], as it helps stakeholders identify patterns or trends, leading to more efficient processes. Visual representations often captivate and clarify more effectively than text-based information, making communicating insights and findings to various organizational-level stakeholders easier. They enhance understanding of complex issues by integrating data from multiple sources and presenting it clearly and succinctly, aiding users/employees' comprehension. Visual aids can be a common language for teams, promoting collaboration and helping members work more efficiently towards shared objectives. Additionally, visual representations can streamline processes, lessen cognitive load, and save time by presenting information in an easily interpretable and actionable format [6].

Throughout the years, data visualization techniques have played a vital role in decision-making, allowing the discovery of significant data points that would be nearly impossible to detect in raw data [7].

The primary objective of this study is to develop a proof of concept of an interactive dashboard that provides up-to-date data on significant business KPI of the seaport industry. This dashboard aims to verify and validate the data that results from data integration from several sources into a single cohesive view, offering flexible display options to satisfy different user profile needs, enable drill-down capabilities for comprehensive analysis, and support proactive decision-making in real-time. For example, the dashboard can display metrics such as the number of vessels berthed per day, average turnaround time per vessel, container throughput per day, and more.

This study will outline the development and implementation of the dashboards, highlighting their role in improving the visibility and management of operational metrics. A literature review will analyse the methodologies and technologies in maritime KPI monitoring and the research gaps that this study aims to address. Subsequently, a detailed description of the dashboards design process will be provided, including selecting relevant KPI, and the integration methods used to ensure real-time data visualization. Additionally, the study is expected to offer insights into how these tools can streamline port operations, provide actionable data for stakeholders, and potentially serve as a model for other seaports.

2. Materials and Methods

The case study that prompted this research is based on the activities developed in the port of Sines, where it was identified which are the involved stakeholders, and the problem statement. The methodological approach of this study was first to identify the improvement opportunities in control and structure of some important indicators within the port management, which could bring many valuable contributions if analysed precisely [8]. Secondly, developing an exploratory literature review, using the Web of

Science, to identify the main KPI, Table 1 to monitor and manage the port industry activities and the most significant indicator standards for port performance management from an operational point of view, and thirdly the evaluation of the datasets provided. Data is valuable only when it can be manipulated in a useful form. Indicators serve this purpose well as they by definition simplify complex phenomena into easily comprehensive figures [9]. Constant meetings with stakeholders contributed to the key performance indicators that will feed the dashboards.

Table 1. Selected KPI

KPI	Variables	Formula
Total Time of Ship Stay with Jurisdiction	Arrival Time; Departure Time	Departure time - Arrival Time
Average Pre-Berthing Waiting Time	Pre-Berthing Time of Vessels sailed; Number of Vessels sailed	Total Pre-Berthing Time of Vessels sailed / Total Number of Vessels sailed
Average Ship Waiting Time	Time when vessels entered anchorage zone; Time when vessels depart anchorage zone; Number of Vessels Sailed	Total elapsed Time from when vessels entered anchorage zone - Total time from when vessels depart anchorage zone / Total Number of Vessels Sailed
Average Container Length of Stay in Yard	Hours at container spends in the port yard; Number of containers	Σ Hours container spends in the port yard / Nº of containers

The research of current solutions in the market for interactive seaport dashboards was crucial to understanding the existing solutions [10], [11], [12]. Also, studying current information visualization tools allowed us to understand the current state of the art in dashboard programming techniques. Moreover, to comprehend dashboard construction, industry experts were consulted to guide the development and implementation process. With this, we establish a robust foundation to support the development of an effective interactive dashboard, aimed at enabling continuous monitoring of KPI and informed decision-making to improve operational efficiency in the port industry.

3. Results and Discussion

This paper contributes to a broader project, in which the managing partner will select the final dashboard configurations—including visualization types, layouts, and hosting environment—to meet specific project needs. The purpose is to deliver a flexible, scientific framework that offers a dynamic and responsive user interface. This will empower decision-makers with real-time data manipulation and analysis, providing a clear perspective on their business mission [13].

The main objective of this work is to evaluate the performance of the port's main operations through a process of continuous improvement, and to define performance indicators through focus group meetings with stakeholders. Data collected at the port highlights key factors but requires further processing to produce relevant indicators. Organizing this data into a dashboard will enhance competitiveness and improve internal port management.

From a business perspective, dashboards can assist managers in visually identifying business trends, patterns, and anomalies. A dashboard can serve multiple purposes: ensuring consistency, facilitating monitoring, assisting in planning, and enhancing communication. Consistency involves standardizing measures and measurement procedures across the different departments; Monitoring involves continuously assessing metrics, leading to necessary corrective actions. In planning, dashboards support the simulation of various future scenarios and dashboards not only communicate performance metrics to stakeholders but also the core values of an organization, as evidenced by the chosen metrics [14].

These KPIs include:

- Average Pre-Berthing Waiting Time: This KPI measures the average time that ships wait before being allocated a berth at the port, helping identify bottlenecks in port entry procedures [15].
- Total Time of Ship Stay with Jurisdiction: This indicator evaluates the total time ships remain under the port's jurisdiction, providing insights into overall port efficiency [16].
- Average Ship Waiting Time: This KPI reflects the average waiting time ships experience in the port, helping to optimize port scheduling and resource allocation [15].
- Average Container Length of Stay in Yard: This KPI tracks the average time containers spend in the port yard, aiding in the management of storage space and container throughput [17].

Ports that actively engage users and their surrounding communities through public dashboards promote transparency in their activities and foster trust. Such dashboards are valuable tools for enhancing community engagement and customer service by providing real-time data and insights into port operations [18].

Implementing dashboards in the complex and volatile port industry offers a comprehensive overview of port performance, significantly enhancing decision-making processes and increasing overall efficiency and effectiveness. By providing an easy and efficient visualization of complex data, dashboards enable decision-makers to make more informed choices.

Moreover, sharing dashboards promotes improved collaboration and transparency among diverse stakeholders. For example, developing and implementing a dashboard for monitoring and controlling container stripping days can significantly enhance a shipping company's efficiency and profitability by facilitating real-time tracking and management of its container assets [19]. Another example, in the context of port operators and trucking companies, dashboards can provide insights into the number of trucks waiting in the queue, their average wait time, and the number of trucks being processed per hour [20].

4. Conclusions

We expect to contribute mainly to (1) identify a small but critical set of KPI needed to monitor and manage key port activities; (2) define algorithms and methods to integrate/combine port data sources properly; and (3) design a reliable proof-of-concept (i.e., a prototype of an interactive dashboard) as a starting point for the development of a complete solution to monitor and manage key port activities.

Summing up, we intend to demonstrate how it is possible to improve operational performance, support strategic alignment and stakeholder engagement in the port sector, and improve decision-making tasks/processes.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).

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Smart Ports and Terminal Logistics: Design and Development of a Business Intelligence System

Marco Gonçalves [1], Cátia Salgado [2] Amaro de Sousa [3], Leonor Teixeira [4*]

[1] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, Aveiro, Portugal; marcofgoncalves@ua.pt
[2] Administração dos Portos de Sines e do Algarve (APS), Sines, Portugal; catia.salgado@apsinesalgarve.pt
[3] Institute of Telecommunications – pole of Aveiro (IT), Department of Electronics, Telecommunications and Informatics (DETI), University of Aveiro, Aveiro, Portugal; asou@ua.pt
[4] Institute of Electronics and Informatics Engineering of Aveiro (IEETA), Intelligent Systems Associate Laboratory (LASI), Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, Aveiro, Portugal; lteixeira@ua.pt
* Correspondence: lteixeira@ua.pt; Tel.: +351-234370361

Abstract: The volume of maritime shipping has increased exponentially, causing serious issues for ports and forcing the adoption of digitalized procedures and more effective solutions. This article details the development of a business intelligence solution based on the CRISP-DM methodology to characterize the flow of container delivery and/or pick-up services at a port terminal in Portugal. The tool was developed with Microsoft Power BI, which enables the extraction and resolution of data nonconformities and presents key performance indicators in visually appealing dashboards. This facilitates the understanding of the present and future operational state and promotes more informed and flexible decision-making. The basis for future BI applications in the Portuguese maritime sector is established by this study, which overcomes data dispersion challenges, enhances logistics flow analysis, and reduces port congestion.

Keywords: Business Intelligence; Data Mining; Performance Indicators; Dashboard; CRISP-DM; Seaports

1. Introduction/Background

Maritime transportation is crucial for global trade, moving 12 billion tons of goods in 2022 [1]. Containers play a vital role in storing cargo and are expected to increase by 3% annually from 2024 to 2028 [2]. This growth highlights the challenges in port logistics, especially at container terminals [3]. Effective terminal operations are essential, requiring swift container movements to reduce peak-time delays and minimize emissions [4]. However, current scheduling systems have not fully addressed these issues.

To address these challenges, ports are increasingly embracing innovation, leading to the development of Smart Ports that use technology to manage disruptions in the supply chain. Automation produces extensive data that needs proper processing for informed decision-making [5]. Many ports still rely on manual procedures, leading to inefficiencies. Therefore, digitalization is crucial for modernization, requiring integrated systems and stakeholder collaboration [6], [7].

The transformation of seaports can be categorized into five generations, each marked by significant technological advancements and operational changes [8]. The first generation, before 1950, saw the shift from manual operations to electronic data interchange (EDI). In the second generation (pre-1980), ports evolved into hubs for value-added services, integrating early port communication systems (PCS). The third generation, starting in the 1980s, introduced intermodal transport and terminal operating systems (TOS), improving efficiency and logistics management. The fourth generation, from the 1990s onward, involved increasingly automated port operations, integrating various systems within unified port administrations. The fifth generation, emerging in 2010, embraced concepts such as "Smart Port," "Industry 4.0," digitalization, and sustainability, using smart devices and centralized control systems [9], [10], [11].

Businesses today handle large amounts of data across their operations, requiring efficient selection and analysis to derive actionable insights [12], [13]. This need has given rise to disciplines like Data Science, which use methodologies such as the Cross-Industry Standard Process for Data Mining (CRISP-DM) and advanced techniques like Data Mining to structure and analyze data effectively [14]. Data mining serves dual purposes: descriptive, to reveal patterns, and predictive, to anticipate future behaviors [15].

In this context, data quality is crucial, encompassing dimensions such as completeness, accuracy, timeliness, consistency, and accessibility [16]. Failures in any of these dimensions can compromise data quality, leading to erroneous decisions and loss of competitive advantage [17]. Therefore, establishing robust quality control policies and processes is crucial to ensure reliable data that supports sound decision-making [18].

Business Intelligence (BI) is essential for effective data utilization, integrating the infrastructure for data extraction, processing, selection, and visualization [19]. The design and implementation of BI systems require strategic planning tailored to each company's specific needs and objectives [20]. Architectural frameworks, such as those proposed in [21], encompass components like Data Sources, ETL (Extract, Transform, Load), Data Warehouse Servers, Data Marts, Mid-tier Servers, and Front-End Applications, ensuring comprehensive and efficient data management.

This paper aims to facilitate the digital and ecological transition in transportation, logistics, and port operations through a decision support system developed using Power BI to structure and accelerate data analysis. The contribution of this study includes the design and development of a practical decision support tool based on Business Intelligence to increase the efficiency and resilience of port logistics operations.

2. Material and methods

The increase in container volume at ports, particularly at the Port of Sines evaluated in this work, puts significant pressure on terminals, highlighting inefficiencies that impact the ability to meet customer demand. One major inefficiency often arises from disorganized logistics services stemming from a lack of demand understanding, leading to operational imbalances.

To address these issues, this study exploits the development of a Power BI application to extract and transform data from logistical operations, enabling quantitative analysis of current and future scenarios. This application aims to enhance decision-making by addressing operational inefficiencies. The methodology employed in this case study is based on the CRISP-DM cycle (see Figure 1), which comprises six phases tailored to the specific requirements and environment of Sines.

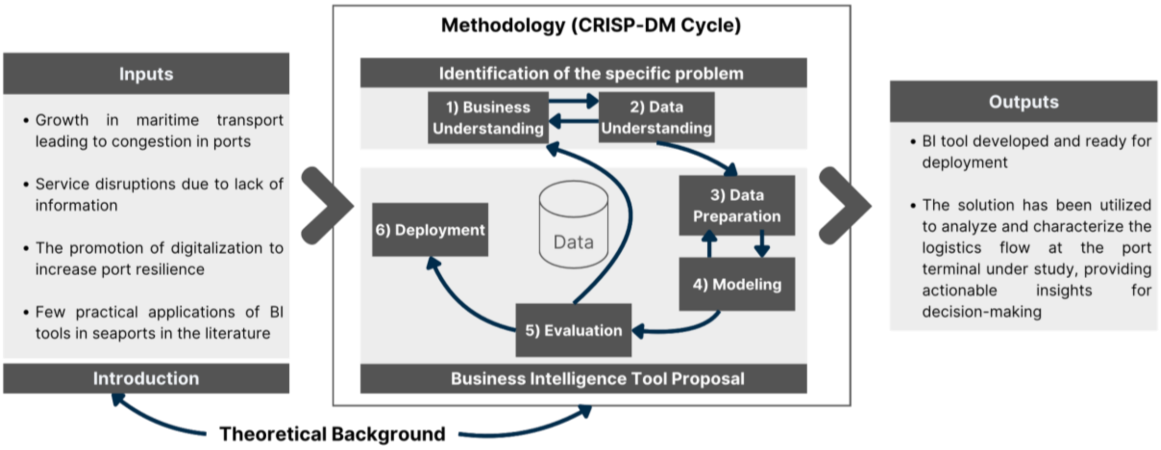


Figure 1. The methodology adopted based on the CRISP-DM cycle

During the initial Business Understanding phase, a series of meetings were conducted to gain a deep understanding of the business and identify areas for improving data analysis and decision-making processes. In the Data Understanding phase, important data sources were identified, and their quality was evaluated, but integrating them posed significant challenges. In the Data Preparation phase, data issues were addressed and the final attributes for the Data Warehouse were selected. The Modeling phase encompassed designing the Data Warehouse and developing dashboards to showcase key performance indicators. In the Evaluation phase, the solution was appraised with a focused assessment of the dashboards to ascertain the new system's effectiveness in analyzing terminal systems and supporting decision-making. Lastly, in the Deployment phase, the process was documented for potential replication in other contexts.

3. Main results

The main achieved results were the definition of a set of useful key performance indicators (KPIs) and their incorporation into the BI tool's dashboards. Fourteen main KPIs (Table 1) were established based on stakeholder requirements and data from the system that supports service scheduling (referred to as JUL) and the system from the company responsible for coordinating terminal activities (referred to as GTOS).

Table 1. Defined KPIs for decision support on logistics services at a port terminal

KPI	Description	Application
No. Appointments	Unique appointment count.	*JUL Analytics*
% Cancellation	Percentage of cancelled appointments.	
Average Appointment Advance	Average time (minutes) between appointment scheduling time instant and the start of the scheduled time window.	
Total Containers per Appointment	Number of containers handled by each appointment.	
No. Services	Unique service count.	*GTOS Analytics*
Average Duration of Service	Average time (minutes) taken per service.	

KPI	Description	Application
% Entry and Exit Same Time Window	The efficiency with which services are performed on time.	
Availability Time Window	Unused capacity within a time window.	
Containers Delivered and Picked Up	Container handling volume.	
% Scheduled Services	Percentage of services scheduled in advance.	
No. Scheduled Services	Total services scheduled in the integrated dataset.	
% Compliance	Percentage of services completed within the scheduled time window.	*INT Analytics*
Average Entry Delay	Average waiting time (minutes) of truck's entry.	
Average Exit Delay	Average waiting time (minutes) of truck's exit.	

Three BI applications were created: JUL Analytics, GTOS Analytics, and INT Analytics. Four dashboards are presented next, with the application and the topic of analysis identified in the top left-hand corner of each one.

The "Categories view" dashboard (Figure 2) displays dynamically two main indicators, depending on the selected category. Once the category is chosen, the top graph shows the Average Appointment Advance, and the bottom graph shows the No. of Appointments for each value within the category that can be viewed daily, as a total, or as a percentage of the total. The importance of this dashboard lies in its ability to analyze appointment data across various categories, enabling users to identify category-specific trends and insights for more targeted decision-making.

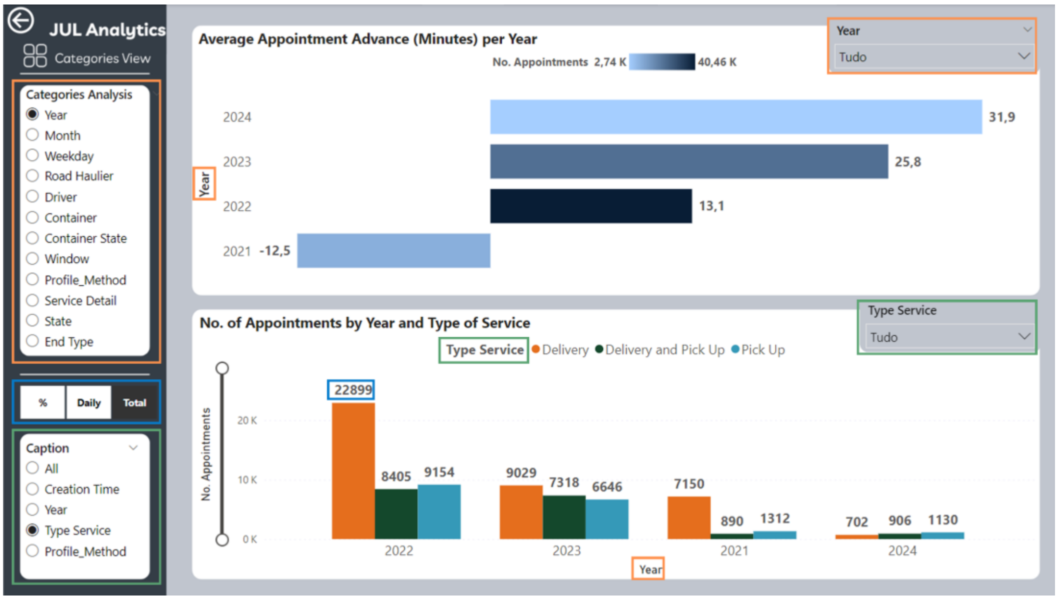
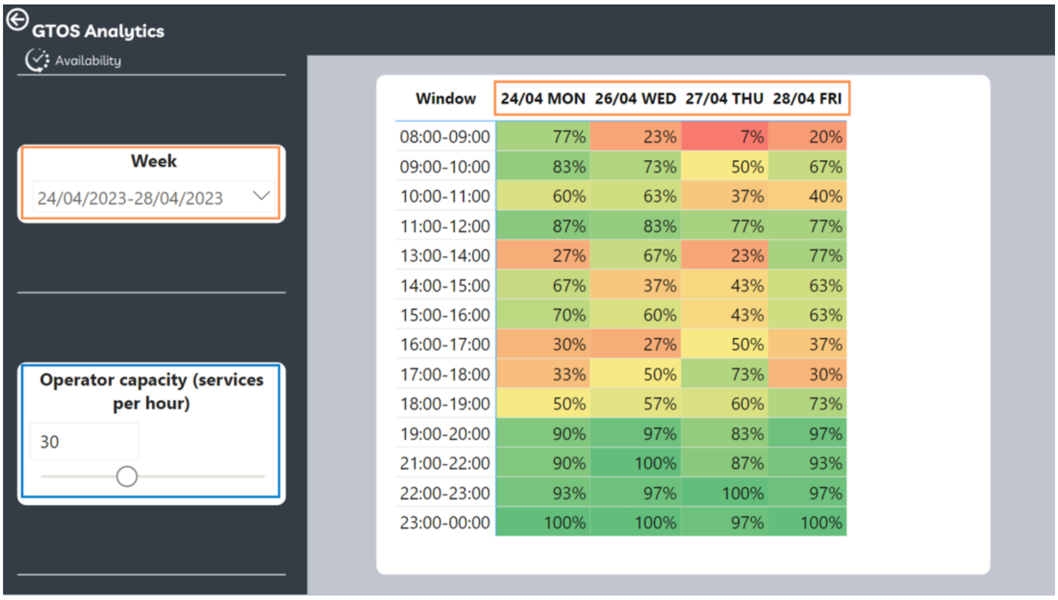


Figure 2. Categories View Dashboard – JUL Analytics

The "Availability" dashboard (Figure 3) displays the Time Window Availability over the week and uses colors to indicate terminal utilization over time: red indicates higher utilization, while green indicates lower terminal utilization. Thus, this dashboard presents a simple visual interface design to offer critical information for both terminal operators and transport companies. It facilitates effective resource allocation management for operators and enables transport companies to plan their operations, thereby preventing unnecessary congestion during peak periods at the terminal.



Window	24/04 MON	26/04 WED	27/04 THU	28/04 FRI
08:00-09:00	77%	23%	7%	20%
09:00-10:00	83%	73%	50%	67%
10:00-11:00	60%	63%	37%	40%
11:00-12:00	87%	83%	77%	77%
13:00-14:00	27%	67%	23%	77%
14:00-15:00	67%	37%	43%	63%
15:00-16:00	70%	60%	43%	63%
16:00-17:00	30%	27%	50%	37%
17:00-18:00	33%	50%	73%	30%
18:00-19:00	50%	57%	60%	73%
19:00-20:00	90%	97%	83%	97%
21:00-22:00	90%	100%	87%	93%
22:00-23:00	93%	97%	100%	97%
23:00-00:00	100%	100%	97%	100%

Figure 3. Availability Dashboard – GTOS Analytics

The "Time View" dashboard (Figure 4) contains the data that has been combined between the two systems (JUL and GTOS). The upper graph of the dashboard shows the values of the chosen indicator across selected periods, allowing users to assess performance trends and absolute quantities over time. Meanwhile, the lower graph offers insights into the indicator's variation, comparing it either monthly or yearly. This comparative analysis aids in identifying seasonal trends, detecting anomalies, and gauging the effectiveness of operational strategies implemented over different time frames. Such insights empower decision-makers to not only react to current trends but also proactively plan for future demands and challenges.

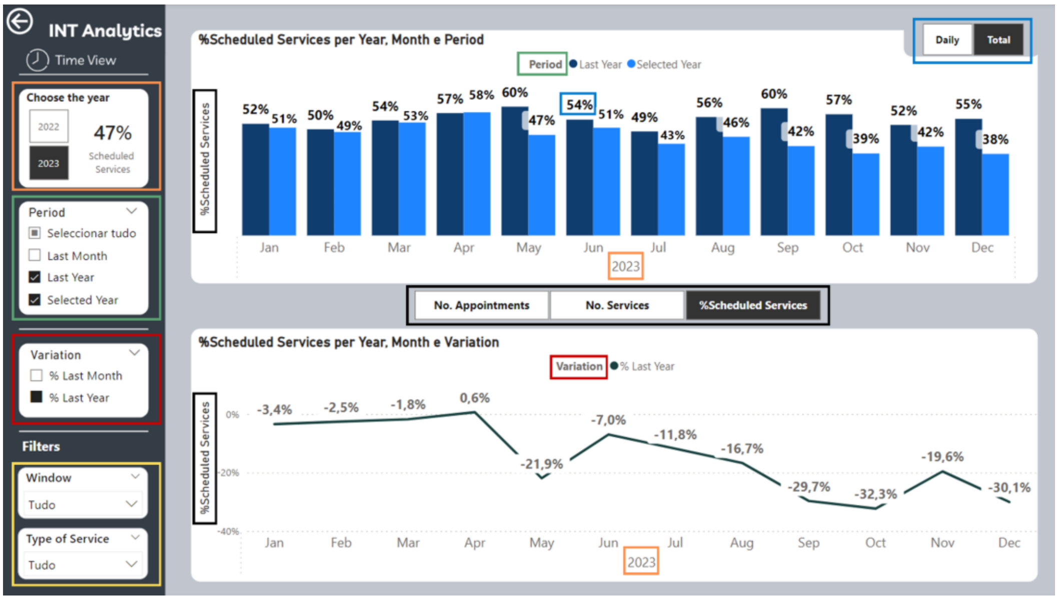


Figure 4. Time View Dashboard – INT Analytics

The "Compliance" dashboard (Figure 5) was created to evaluate whether hauliers and their drivers comply with the scheduled time window for service. This dashboard consists of four graphs, each providing different analytical perspectives. Users can select indicators and categories for detailed analysis. The top left graph presents values of the selected indicator across different elements of the chosen category. Meanwhile, the bottom left graph displays the '%Compliance of these category elements. On the top right, users can explore how category values correlate with the number of scheduled services. Finally, the bottom right graph presents the distribution of services based on compliance with designated time windows, featuring interactive filtering options that synchronize with selections made in other graphs. As a result, this specific dashboard exemplifies the successful integration of data from various systems, facilitating innovative analysis of terminal operations.

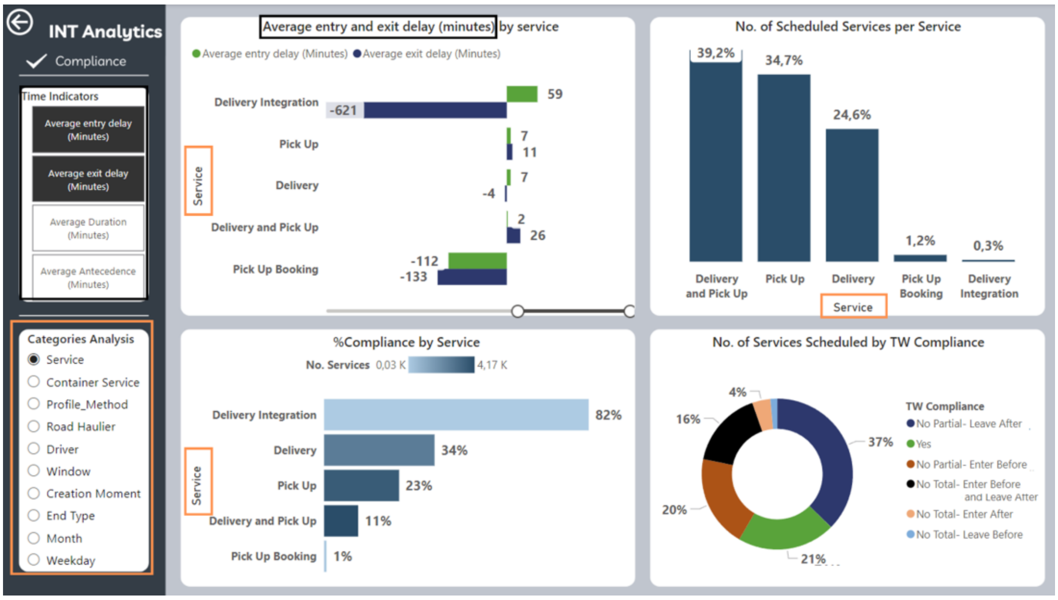


Figure 5. Compliance Dashboard – INT Analytics

After a thorough review of the BI tool with key stakeholders to assess its potential impact and its capacity to measure and analyze parameters, and after gathering feedback during validation meetings on the impact of the solution at the port terminals, the BI solution has shown to improve significantly data analysis, as it now provides quick access to critical KPIs that were previously difficult to obtain. This tool allows stakeholders to make better-informed decisions, with an improved analysis in terms of depth and accuracy.

4. Conclusions

Data is an invaluable resource for businesses since it facilitates prompt and well-informed decision-making. To guarantee that data is easily accessible and tailored, business intelligence technologies are essential in redefining data collection, processing, and dissemination processes. By analyzing and interpreting data, these technologies transform it into valuable information for informed decision-making. This study focused on the challenges in handling data across several information systems, which have been constraining a Portuguese seaport's ability to make decisions. A customized business intelligence tool was developed to improve logistics flow analysis, and it has shown to be successful in practical situations. This digitalization with a BI focus handles information gaps, improves overall structured analysis, and enables data-driven decision-making. The success of the tool suggests that it can be used in other port terminals to improve the resilience and efficiency of logistics operations. Future research should focus on the application of BI in the maritime sector, examining case studies from various terminals to evaluate its scalability and suitability for optimizing port operations.

Author Contributions: Conceptualization, M.G, A.S and L.T.; methodology, M.G., C.S., and L.T.; validation, C.S., A.S. and L.T.; formal analysis, A.S. and L.T; writing—original draft preparation, M.G.; writing—review and editing, M.G, A.S., and L.T..; supervision, L.T.; funding acquisition, L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the PRR - Recovery and Resilience Plan and by the NextGenerationEU funds at Universidade de Aveiro, through the scope of the Agenda for Business Innovation "NEXUS: Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade" (Project no.53 with the application C645112083-00000059).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to private issues.

Conflicts of Interest: The authors declare no conflicts of interest.

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Temporal Analysis of the shipping movements at the Port of Sines (2010 - 2023)

Teresa Batista [1]*, Luís Rosa[1], Francisco Borges[1], Crismeire Isbaex[1] and Samuel Martins[2].

[1] MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, Institute for Advanced and Research, Universidade de Évora, Évora, Portugal.
[2] APS - Administração dos Portos de Sines e do Algarve, Sines, Portugal.
* Correspondence: mtfb@uevora.pt. Tel.: +351 963 257 296

Abstract: In port operations, an efficient maritime transport system provides competitive advantages by optimizing cargo flow and minimizing ship waiting times. Aiming to contribute to the sustainability, this study investigates the dwell time of ships at the Port of Sines and each one of its five terminals. Based on vessels dwell time data between 2010 and 2023, 157,515 records were analysed related with the different maneuvers in the port. A statistical analysis processed using Python was conducted to analyse the average time of vessel calls in the port's jurisdiction area, and for each terminal. This analysis permitted addressing the port efficiency level in relation to the global standards and the obtained results confirmed that ships spend significantly less time in the port area of Sines compared to the average of the 25 largest economies in the world ports.

Keywords: Port Efficiency; Port Operations; Dwell Time; Maritime industry; Just-in-Time.

1. Introduction

Maritime transport handles approximately 90% of global trade, making it crucial to the international economy and critical in supporting global supply chains. Efficient port operations play a pivotal role in ensuring the flow of goods, minimizing costs, and maintaining schedule reliability across the supply chains [1]. While the time that vessels spend at port is relatively brief compared to their time at sea, inefficient port operations can cause major delays, disrupting logistics, raising costs, and increasing environmental impact.

In ports, a vessel's dwell time encompasses various activities, including loading, unloading, and essential procedures. Prolonged dwell time are often associated with factors such as poor communication between port stakeholders, inadequate scheduling, and unexpected operational risks, resulting in longer berth waiting times and potential congestion [2, 3]. Excessive wait times for berthing also contribute to higher fuel consumption and greenhouse gas emissions. This environmental impact is particularly concerning in light of increasing global efforts to reduce emissions [4-6]. A study conducted by the United Nations Conference on Trade and Development (UNCTAD) suggests that the average time a ship spends in port is approximately 1.16 days among the largest 25 global economies, according to MarineTraffic data [7]. While previous studies have explored several methods for measuring and improving port efficiency, such as data envelopment analysis (DEA) [8,9], stochastic frontier analysis (SFA) [10, 11], ordinary least squares (OLS) [12], analytic hierarchy process (AHP) [13-14], and directional distance function (DDF) [15], is important to notice that fewer studies focus on evaluating the vessel's dwell time within different operational zones inside a port, from entry to exit of the vessel traffic service (VTS) area [16, 17].

In this context, the aim of this study is to analyze the spatial-temporal trajectories within the Port of Sines, focusing on the time and vessel movement. The findings contribute to a broader understanding of port efficiency dynamics and suggest potential strategies, such as Just-in-Time (JIT) arrivals. These strategies not only reduce emissions but also promote more environmentally friendly port operations. Specifically, JIT can decrease emissions and fuel consumption by 2 to 20% [18-20]. Integrating JIT into port operations requires meticulous coordination and collaboration among all stakeholders [21].

2. Materials and Methods

This study employs a combination of bibliometric analysis and a descriptive statistical method to investigate vessel dwell time and port efficiency at the Port of Sines, Portugal. By systematically analyzing historical records of vessel movements, this section aims to detail each methodological step, providing a reliable foundation for assessing temporal efficiency and identifying areas for operational improvement.

2.1. Bibliometric Analysis

To establish a theoretical foundation, a bibliometric analysis was conducted to explore the existing body of the research on port efficiency and vessel dwell time. This step ensures that the study builds upon and aligns with established knowledge in the maritime operations field. The bibliometric analysis focused on the research question, "How does vessel dwell time affect port efficiency?" guiding the selection of relevant publications and keywords. Data was sourced from the Web of Science using terms like "Port Efficiency," "Port Operations," and "Ship Time." Keyword co-occurrence was analyzed with VOSviewer 1.6.20, identifying thematic clusters within the research. Publications meeting the inclusion criteria were then organized in EndNote X9 to enable systematic tracking of sources.

2.2. Data Collection and Pre-Processing

Data on vessel movements within the Port of Sines from 2010 to 2023 were provided by the Administration of the Ports of Sines and Algarve, SA (APS). The data were sourced from two key databases: Single Port Window (2010-2021) and the Logistics Single Window (2021-2023). These records include timestamps and descriptions for each vessel movement (Table 1).

Table 1. Glossary of each of the vessel's movements.

Glossary – Analysis of ship movement data	
PLF – Entrada	Vessel's entry into the port's jurisdiction area
Fundear	Anchor the vessel in the anchorage areas.
Saída - Para Pairar	Leaving the port area to wait for the possibility of berth.
Entrada - De Pairar	Entry into the port area to dock after hovering.
Suspender	Weigh anchor to depart.
Atracar	Maneuver to berth the vessel into the terminal.
Largar	Departure of the vessel from the terminal.
PLF – Saída	Vessel's exit from the port's jurisdiction area

To ensure the data's accuracy, a pre-processing procedure was applied, including data quality check, data categorization and data curating.

2.3. Statistical Analysis of Vessel Dwell Time

The analysis of vessel dwell time and movement was performed using Python in a Jupyter Notebook environment, focusing on descriptive statistics to capture average times across different stages and terminals. This approach provided a comprehensive view of time efficiency within the port’s jurisdiction.

3. Results and Discussion

Figure 1 presents a keyword cloud generated by VOSviewer. This analysis underscores the growing emphasis on sustainability in port operations. Reducing dwell time and optimizing maneuver efficiency are key strategies to decrease fuel consumption and emissions, directly supporting environmental goals. The strong linkage between keywords such as "efficiency," "sustainability," and "emissions" in the analysis reinforces that operational improvements can have a direct impact on reducing the port's carbon footprint.

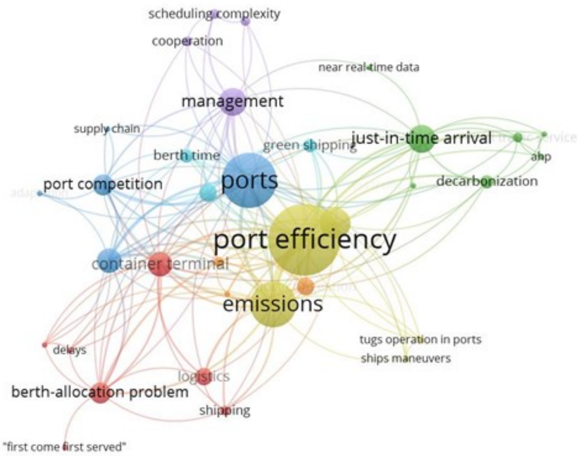

Figure 1. VOSviewer keyword cloud.

Figure 2, illustrates the number of vessel entries at the Port of Sines from 2010 to 2023. In this case, there were 29 567 vessels entering the port between 2010 and 2023.

This analysis suggests an overall upward trend in port activity. The increasing volume of vessels entering the port reflects the Port of Sines rising significance within the maritime industry. While growth has not been entirely linear, this trend aligns with the port’s expanding role in international trade.

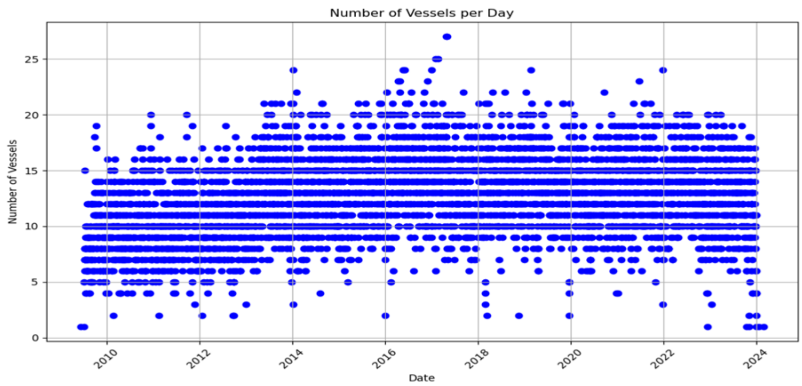

Figure 2. Number of vessel entrances at the Port of Sines between 2010 and 2023.

The average dwell time for vessels at the Port of Sines was found to be 0.55 days, significantly shorter than the UNCTAD average of 1.16 days. Although the result indicates that the Port of Sines operates at a high level of efficiency compared to other ports worldwide, dwell time varied significantly across terminals, with Container Terminal showing a particularly efficient dwell time, while the Multipurpose Terminal exhibiting the most inefficient. Table 2 presents the Port Terminal Operations Summary, exhibiting a detailed view about the number of vessel entries, dwell times, berth and anchoring metrics.

Table 2. Port Terminal Operations Summary: Vessel Entries, Dwell Times, Berth and Anchoring Metrics.

Terminal	Total Number of Vessel entries	Average number of Vessel entries (per year)	Average Dwell Time (in days)	Overall Anchoring consuming Time (in days)	Overall Berth consuming Time (in days)	Percentage of Vessels that Anchor (%)
Liquid Bulk Terminal	10 473	748	0.59	0.19	0.38	60
Petrochemical Terminal	1 811	129	0.55	0.18	0.35	46
Multipurpose Terminal	3 101	222	1.08	0.35	0.69	20
Liquified Natural Gas Terminal	649	46	0.60	0.19	0.38	11
Container Terminal	13 533	967	0.38	0.12	0.24	18
Port Total	29 567	2 112	0.55	0.18	0.35	38

In this study, it was found that the dwell time is influenced by the anchoring stage, which corresponds approximately to 9% of the total movements in port. Despite this, approximately 38% of vessels entering the port anchor. The Liquid Bulk Terminal had the highest anchoring frequency, occurring in 60% of vessel entries.

Maneuvers such as berthing and anchoring showed consistent execution times throughout the studied period and together accounted for a notable portion of overall vessel dwell time. Figure 3 shows the evolution of time spent on each maneuver, offering insights into operational changes over time. The data reveal that the duration of anchoring maneuvers ("Fundear") has increased since 2016, with fluctuations suggesting periodic congestion or operational adjustments.

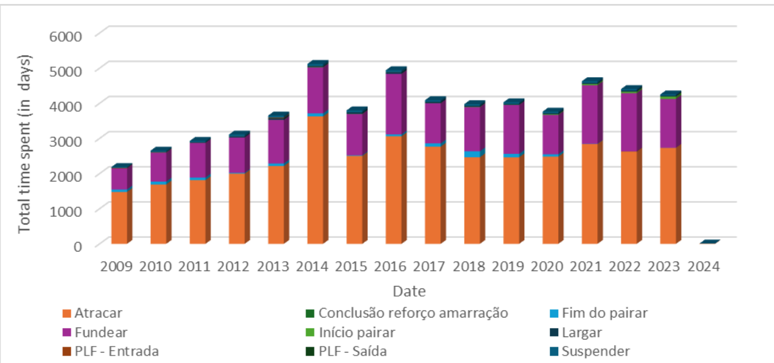

Figure 3. Time spent by vessels in each maneuver between 2009 and 2024.

The time consumed by the maneuvers "Atracar" and "Fundear" (berthing and anchoring) exhibited fluctuations that suggest the need for improvements. Elevated anchoring rates, specifically regarding the Liquid Bulk Terminal (60%) and Petrochemical Terminal (46%) underscore the importance of enhancing berth management. Implementing predictive scheduling and real-time stakeholder communication could reduce waiting times and anchoring frequency, thereby helping to prevent congestion during peak periods. These strategies align with findings from studies addressing port congestion challenges.

When benchmarked against global averages, the Port of Sines demonstrates strong operational efficiency with a vessel dwell time significantly below the average of the top global economies.

4. Conclusions

The Port of Sines can be considered efficient from a global average perspective when considering the average time ships spend within the port area. Yet, it faces challenges with prolonged anchorages, indicating a critical area for improvements that can significantly boost the port's overall competitiveness.

In this context, the findings suggest that the implementation of a Just-In-Time (JIT) approach could mitigate the dwell times associated with frequent anchorage, thereby improving operational efficiency, productivity, and overall competitiveness in the Port of Sines.

Acknowledgements

Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project nº 53).

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On-demand 5G Private Networks using a Mobile Cell

André Coelho*, José Ruela, Gonçalo Queirós, Ricardo Trancoso, Paulo Furtado Correia, Filipe Ribeiro, Helder Fontes, Rui Campos, Manuel Ricardo

INESC TEC, Faculdade de Engenharia, Universidade do Porto, Portugal;
* Correspondence: andre.f.coelho@inesctec.pt;

Abstract: This paper proposes the Mobile Cell (MC) concept for on-demand 5G private networks. The MC is designed to extend, restore, and reinforce 5G wireless coverage and network capacity on-demand, especially in areas with temporary communications needs or where it is costly or not possible to deploy a permanent fixed infrastructure. The design of the MC as well as the development, integration, and deployment in 5G private networks are discussed.

The Mobile Cell concept can be applied in multiple real-world environments, including seaports and application scenarios. Similarly to critical hubs in the global supply chain, seaports require reliable, high-performance wireless communications to increase efficiency and manage dynamic operations in real-time. Current communications solutions in seaports typically rely on Wi-Fi and wired-based technologies. Wired-based technologies lack the necessary flexibility for dynamic environments. Wi-Fi is susceptible to interference from other systems operating in the same frequency bands. An MC operating in a licensed, interference-free spectrum is a promising solution to overcome these limitations and provide improved Quality of Service when using the 5G technology.

Keywords: 5G; Mobile Cell; NPN; On-demand Network; Radio Access Network; Seaport Communications.

1. Introduction

International seaports play a key role in trade, logistics, and the global supply chain. To improve operational efficiency and minimize costs, there is an increased interest in integrating novel technological solutions in seaports, including video surveillance, autonomous vehicles, and mission-critical communications. This will allow for environment-aware, data-driven aided decisions and adaptive management of the seaport operations in real-time [1–3].

When it comes to communications, many seaports, including the Port of Sines in Portugal, currently rely on Wi-Fi and wired-based technologies [4]. Wired-based technologies offer limited flexibility for dynamic networking scenarios. Wi-Fi is prone to interference from other systems operating in the same frequency bands, including interference from ships' radars when they dock at the seaport, leading to communications disruptions. This reduces network reliability and availability, compromising the overall performance.

The 5G technology, known for supporting enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and Ultra-Reliable Low-Latency Communications (URLLC), operating in a licensed, interference-free spectrum, is a promising solution to meet heterogeneous requirements associated with key use cases [5]. Still, Radio Access Networks (RANs) typically rely on fixed Base Stations. In seaport scenarios, unexpected obstacles and machinery frequently compromise signal propagation. On the other hand, the dynamism of a multitude of operations carried out simultaneously imposes fluctuations in traffic demand.

On-demand wireless networks, with dynamic reconfiguration and repositioning capabilities, have emerged as a suitable solution to extend, restore, and reinforce wireless coverage where a fixed infrastructure is non-existent, insufficient or damaged. An on-demand network infrastructure leveraging 5G technology can improve the Quality of Service (QoS) offered to end-users in dynamic environments, such as seaports.

This paper describes the architecture, design, and development of a Mobile Cell (MC) for on-demand 5G private networks. The 5G MC enables the RAN to be reconfigured and repositioned over time, allowing for the extension of fixed communications infrastructures. This solution holds the potential to offer wireless connectivity anywhere in a seaport environment, especially in areas with temporary communications needs or where fixed infrastructures may not be feasible and cost-effective.

In this paper, the concept of MC refers to a mobile base station or a mobile base station relay, as described hereafter. The main goal of a 5G MC is to extend the coverage of a 5G network to zones where a User Equipment (UE) is out of reach of the fixed 5G infrastructure [6], which may be either a Public Land Mobile Network (PLMN) or a Non-Public Network (NPN).

As a downgraded version, an MC can be deployed as a nomadic node, placing it in a predefined, quasi-static position where it stays while needed, in order to reinforce capacity or provide 5G access where it is unavailable. This may be the case of temporary events and emergencies. In a seaport environment, an MC can be carried, for example, on ground vehicles, towboats, or drones, requiring a 5G wireless connection to the fixed infrastructure, as illustrated in Figure 1.

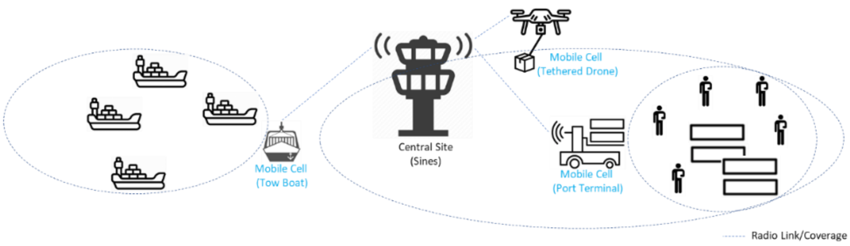

Figure 1. Mobile Cell (MC) carried by ground vehicles, towboats, or drones in a seaport scenario.

The MC aims at extending a 5G RAN [7] provided by a PLMN or an NPN to areas with limited wireless connectivity and network capacity, including offshore locations in seaport environments.

2. Reference Architecture

For a better understanding of the MC functional elements, the 5G RAN architecture is first described. The basic 5G RAN node is a base station called gNodeB (gNB). Besides the Radio Frequency (RF) unit, the 5G RAN functions implemented by gNBs are divided into various protocol layers, as shown in Figure 2: Physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Radio Resource Control (RRC).

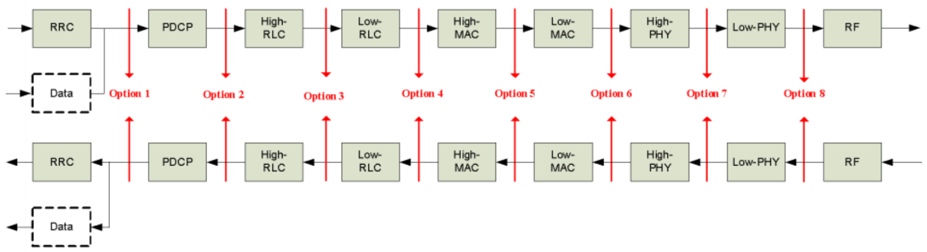

Figure 2. Function Split between central and distributed unit [8].

Figure 2 also shows eight possible functional split points that may be used to group functions into three functional units: a Central Unit (CU), a Distributed Unit (DU), and a Radio Unit (RU). A High-Level Split (HLS) separates the CU from the DU, while a Low-level Split (LLS) separates the DU from the RU. This allows multiple network configurations, with different physical and logical grouping and location of functions.

The 3rd Generation Partnership Project (3GPP) defined a Next Generation RAN (NG-RAN) architecture [9] composed of multiple gNBs. A gNB consists of one or more DUs controlled by a single CU, as illustrated in Figure 3.

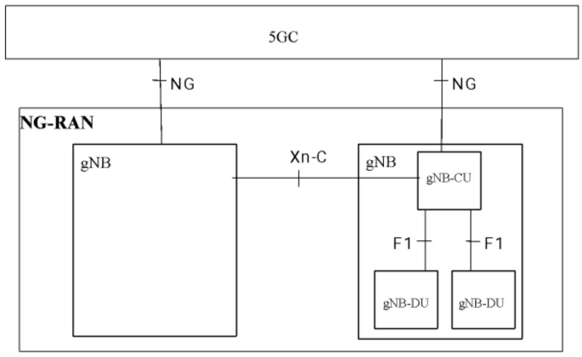

Figure 3. Overall NG-RAN Architecture [9].

For the CU/DU HLS, 3GPP adopted option 2, that is, the CU implements the RRC and PDCP protocol layers, and specified the IP-based F1 interface [10] for the communications between the CU and the DUs. Since this architecture does not impose any LLS, the RU functions are not explicitly represented.

The enhanced Common Public Radio Interface (eCPRI) [11], based on split 7.2, is a standardized LLS interface.

For the design of the MC, latency and throughput requirements on HLS and LLS interfaces were taken into account.

The MC is a mobile node hosted by a 5G network (PLMN or NPN), which provides the 5GC functions. It is either a full gNB or a relay node with DU and RU functions; in the latter case, the CU is part of the fixed 5G infrastructure. A 5G radio link is required to connect the MC to the hosting network.

3. Design and development

To achieve a proof of concept of the MC, we propose two alternative architectures: the MC is a full mobile gNB (no CU/DU split) or a mobile DU/RU relay controlled by a fixed CU (split 2).

In both solutions, it is necessary to establish IP connectivity between the MC and its home fixed network infrastructure, which includes 5G Core functions. For this purpose, a 5G Protocol Data Unit (PDU) session must be set-up by an overlay network (ON) between the MC and a User Plane Function (UPF) on the ON. The ON may be the home network (HN), for example a Standalone NPN, or a Mobile Network Operator (MNO) PLMN, when the MC is not within the range of a fixed gNB of the HN.

To set-up the PDU session, the MC acts as a regular UE, which is represented by a Mobile Termination (MT) function. First, a 5G wireless channel is set-up between the MT and a gNB on the ON and, once established, the MT PDU session is used to transparently carry all UE data and control traffic to the HN, through the MC and the ON.

The two MC-proposed solutions are agnostic to the architecture of the ON gNB(s), since the MC only requires the establishment of an MT PDU session. They differ on the endpoints (on the mobile platform and the fixed infrastructure) of the MT PDU Session.

An MC based on a no split architecture is a full gNB consisting of RU, DU, and CU entities placed on-board a mobile platform, while the 5GC functions reside on the fixed HN infrastructure. An MT function, acting as a UE, is employed to establish IP connectivity between the CU and the 5GC network through an ON, as explained before. This solution is depicted in Figure 4.

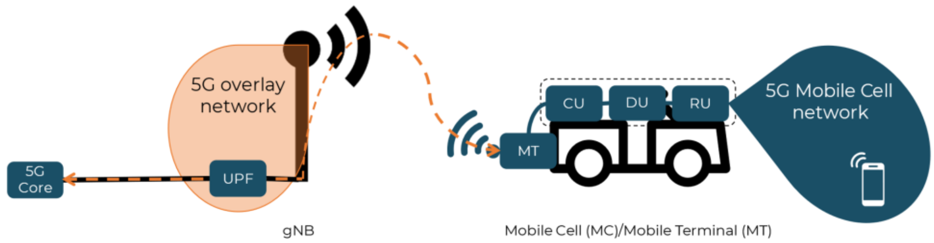

Figure 4. Solution based on CU, DU and RU on-board a mobile platform.

An MC based on the CU/DU split 2 architecture consists of a DU and an RU placed on-board a mobile platform, while the CU and the 5GC functions are part of the fixed HN infrastructure. Communications between the DU and CU entities take place over the F1 interface. First, the MT function must trigger the establishment of connectivity at IP level through an ON, as explained. This solution is depicted in Figure 5.

The connection between the CU and the 5GC network function is typically ensured by a wired link, such as optical fibre.

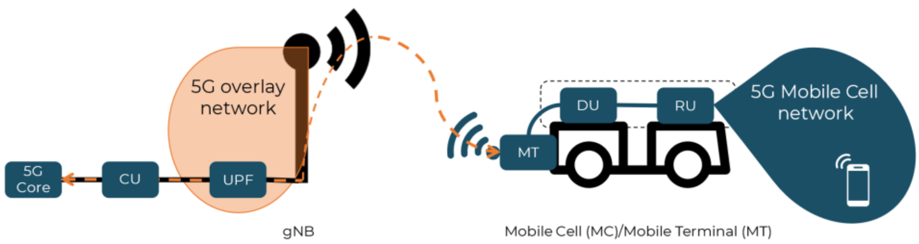

Figure 5. Solution based on DU and RU on-board a mobile platform and CU on the fixed infrastructure, close to the 5GC network.

4. Discussion

The MC solutions may be assessed and compared using as reference the architectures currently proposed by 3GPP.

The high-level specification of a mobile base station relay (MBSR) that takes advantage of the Integrated Access and Backhaul (IAB) architecture [9][12] is described in [8]. An IAB network is organised as a logical tree of IAB-nodes, with an IAB-donor at the root. An IAB node is composed of an IAB-DU and an IAB-MT function. The IAB-donor is based on the gNB CU/DU split 2 architecture and consists of a single IAB-donor-CU and one or more IAB-donor-DUs. The communications between the IAB-donor-CU and all DU entities take place over the F1 interface. The branches of the tree are wireless backhaul links (between a DU on a parent node and an MT on a child node), which are used to relay traffic between IAB-nodes and the IAB-donor. The DU entities also provide wireless access links to UE. An IAB MBSR is just a mobile IAB-node directly attached to the IAB-donor-DU, using the respective access link.

Unlike the MC split 2 architecture, the MBSR-DU is controlled by the same entity (IAB-donor-CU) that provides access to the 5G Core. Moreover, a Backhaul Adaptation Protocol (BAP) layer is required on all IAB DU and MT entities, on top of RLC/MAC/PHY layers; it maps IP packets (carried over the F1 interface) into RLC channels for relaying across backhaul links. For this reason, to directly attach to an IAB-donor, the MC split 2 architecture would have to be upgraded by adding BAP to the MC-MT stack.

Anyway, the current MC solutions allow attaching to an IAB network in the overlay mode – the IAB-donor is used as a conventional gNB, as also seen by UEs.

3GPP is currently promoting the study of a mobile gNB, under the designation of Wireless Access Backhaul (WAB) [13]. In architectural terms, this corresponds to the MC architecture with no CU/DU split. This solution has some advantages over the MC split 2 architecture: 1) it avoids the complexity of the F1 interface; 2) does not require an MC-CU on the fixed infrastructure; and 3) does not need tight control of the delay between the MC-DU and MC-CU as when connected by an ON. In addition, a 5G Core with basic functions may be deployed on the MC, thus providing some local services to UEs. This MC platform will be a valuable tool for research aligned with the WAB proposed objectives.

5. Conclusions

Private communications networks based on 5G technology are being deployed with success in seaports worldwide. In such environments, on-demand networks offer improved flexibility due to their reconfiguration and repositioning capabilities. In this context, mobile communications platforms based on the MC concept may play a new and important role, since they can be deployed on-demand to take advantage of their properties. They allow extending coverage and capacity of fixed communications infrastructures, potentially offering 5G wireless connectivity anytime and anywhere in the seaport.

The proposed MC has the potential to offer: 1) enhanced flexibility, allowing it to meet variable network requirements through dynamic repositioning; 2) scalability, as the number of MCs can be increased to extend network coverage without significant changes to the network infrastructure; and 3) cost-effectiveness, since MCs can reduce the need for fixed, permanent communications infrastructures with scarce use in some locations. The usage of MCs is especially relevant in areas with temporary communications needs or where fixed infrastructures may not be feasible or cost-effective.

For future work, we aim at implementing an MC for a real-world proof of concept in a seaport environment with representative use cases.

Author Contributions: Conceptualization, A.C., J.R., P.F.R., F.R., H.F., R.C., M.R.; methodology, A.C., J.R., F.R., H.F., R.C., M.R.; software, G.Q., R.T.; validation, A.C., G.Q., R.T.; investigation, all authors; writing—original draft preparation, A.C., J.R.; writing—review and editing, A.C., J.R., H.F., R.C., M.R.; supervision, M.R.; funding acquisition, F.R., H.F., R.C., M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This work is co-financed by Component 5 - Capitalization and Business Innovation, integrated in the Resilience Dimension of the Recovery and Resilience Plan within the scope of the Recovery and Resilience Mechanism (MRR) of the European Union (EU), framed in the Next Generation EU, for the period 2021 - 2026, within project NEXUS, with reference 53.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Predicting usage for a cloud-based Access Control System

Joana Oliveira*, Vítor Barbosa and Ana Mendes

RESILIENCE - Center for Regional Resilience and Sustainability, Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campos do IPS - Estefanilha, 2910-761 Setúbal, Portugal; 220353012@estudantes.ips.pt; vitor.barbosa@esce.ips.pt; ana.mendes@esce.ips.pt

* Correspondence: author

Abstract: The NEXUS Agenda [1] is a project aimed at driving digital and sustainable transformation in the transport and logistics sector. Access control will be one of the areas addressed and plays a fundamental role in data and facility security. For effective access control, it is essential to perform authentication and validation of authorizations. The servers responsible for handling these service requests incur significant costs. Given that the flow of people, containers, and other items fluctuates, the required server capacity also varies through the day and between weekdays and weekend days.

As a contribution to the Cloud 4 Access Control product, in this research, we intend to identify the major clients' service requests patterns, define which variables and distributions can be used to describe each client type pattern and, using those inputs, explore predictive models to create a model capable of predicting the service usage, in fixed size time slots, considering the client profiles, dimensions (number of users) and request patterns. The created model should be capable of predicting the service usage, for specific time slots, to determine the number of servers needed by each hour. That way, we can predict the number of servers needed and plan their allocations accordingly to the demand, being efficient and reducing costs.

Predictive models can play a crucial role, helping to implement a robust and scalable solution that can dynamically adjust to the changing needs, ensuring both high performance and cost efficiency. These models can assist by analysing historical access data, such as days, hours, and number of accesses.

Keywords: Digital Transformation; Access Control; Authentication and Validation; Traffic Prediction, Predictive Models

1. Introduction

The question addressed in this research is set within the broader context of cost reduction and efficiency in the transport and logistics sector, specifically within port facilities, which is the main goal of the NEXUS Agenda [1]. The primary purpose of this study is to explore and implement a predictive model that can predict demand flow from different clients and profiles to always know the necessary access control service capacity to efficiently use it and minimise the costs of the used infrastructure. The Cloud 4 Access Control service intends to develop scalable solutions that dynamically adjust to fluctuating demands, thereby improving both performance and cost-efficiency when providing access control considering the flow of people and goods in port areas.

The access control in port areas is very important because of the high flows of people and vehicles that must be accurately checked and controlled [2, 3].

Most of the literature about access control is focused on information systems and digital resources, but some of the concepts are shared [4]. A user or a group of users has a set of permissions (roles) granted for a limited set of resources.

This research is related to the development of the Cloud 4 Access Control service, but the objective is to predict the demand of requests from the multiple clients of the service, either they are ports or other types of organizations that sign up for the service. Predicting the demand of request accesses will allow entities to plan how they allocate the resources needed and reduce costs, decreasing the use of resources when there's no need for them.

The predictive model proposed in this study will be developed from historical access data, including the number of accesses, timestamps, the type of requests and other variables. Those usage patterns, combined with the information about the profiles of the clients (dimension, services used, etc) will allow to develop the final predictive model to be used as a source of information to prepare the infrastructure to assure the quality of service, without wasting resources.

Additionally, the implementation of such predictive models will not only improve operational efficiency but also enhance security protocols by anticipating peak times and potential vulnerabilities. The research will delve into various AI techniques, such as machine learning algorithms, to develop an effective predictive framework. This approach will ensure that the port facilities can maintain high levels of security and operational efficiency without incurring unnecessary costs.

The outcomes of this study are expected to contribute significantly to the digital transformation of port operations, setting a precedent for other sectors within the transport and logistics industry. By demonstrating the effectiveness of AI-driven predictive models in optimizing resource allocation and improving security measures, this research will pave the way for more innovative and cost-effective solutions in managing critical infrastructure.

2. Materials and Methods

In this study, a comprehensive literature review was conducted to consolidate fundamental concepts and identify key scientific articles related to access control and traffic prediction. The primary objective of this review was to assess the current state of the art, examine the existence of similar problems, the methods employed, and the evaluation methods used in the field of traffic forecasting.

Firstly, we explored foundational concepts in predictive modelling [5, 6, 7, 8] and access control within the transport and logistics sector [9, 10]. By establishing a theoretical framework, we aimed to provide a solid basis for the subsequent analysis and discussion.

Next, we searched for scientific articles and research papers that specifically addressed traffic prediction in port facilities and similar contexts. Articles were selected based on their relevance and the methodologies employed. Reviewing the state of the art, permitted us to understand the different ways to approach traffic flow predictions. We understood the specificities of the topic, familiarized ourselves with the most commonly used algorithms for these kind of problems and studied various algorithm evaluation methods, understanding each one's purpose and identifying the most commonly used approaches.

The review also included an evaluation of the main algorithms used for traffic prediction. We identified various machine learning techniques such as regression analysis, neural networks, decision trees, and support vector machines [11, 12, 13, 14, 15, 16, 17, 18, 19]. The strengths and weaknesses of each algorithm were analyzed, considering factors such as accuracy, computational efficiency, and scalability. This analysis provided insights into which algorithms were most effective for predicting traffic flow in dynamic environments.

Furthermore, we investigated the evaluation methods used to assess the performance of these predictive models. Common metrics such as Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE) were reviewed. These metrics helped us understand how different models were benchmarked and the standards of accuracy expected in the field. There is no single solution; among the methods most frequently cited in the articles we reviewed, we will test several to determine which yields the best results. As for the evaluation approach, it will always depend on the business problem and our priorities—whether accuracy or other factors are more critical.

By consolidating these findings, the literature review offered a comprehensive overview of the current landscape in traffic prediction. This groundwork informed the development of our own predictive model, ensuring that it was built on the most effective algorithms and evaluated using robust, industry-standard methods. The insights gained from this review are crucial for advancing the efficiency and cost-effectiveness of access control in port facilities, ultimately contributing to the broader goals of the NEXUS Agenda.

3. Results

In this study, we aim to apply the CRISP-DM (Cross-Industry Standard Process for Data Mining) methodology [20, 5] to develop a predictive model for optimizing access control and resource allocation in port facilities. Although the research is ongoing, we anticipate several key findings that will significantly contribute to the field.

We consider it important to use the CRISP-DM methodology because it is a standard process for predictive modelling projects. It defines an organized structure with six main phases: business understanding, data understanding, data preparation, modeling, evaluation and deployment. It also provides a clear and repeatable structure that helps guide work with predictive models reducing its errors.

Firstly, by following the CRISP-DM methodology, we expect to thoroughly understand the business context and requirements for effective access control in port areas. This initial phase will involve defining the objectives, understanding the data, and preparing it for analysis. We will gather data related to traffic flow, access times, and user profiles to build a comprehensive dataset that reflects the dynamic nature of port activities. For that we did an extensive literature review, to understand the main issues and solutions when solving traffic predictions problems. This initial phase involves defining the objectives, in this case, predicting the number of accesses per time slot to plan the servers allocation needs and reduce costs.

During the data preparation phase, we will clean and preprocess the collected data to ensure its quality and suitability for predictive modelling. This step is crucial for eliminating noise and inconsistencies, thereby enhancing the accuracy of our model.

While conducting an exploratory data analysis, we expect to identify patterns and trends within the data that will inform the development of our predictive algorithms.

The modelling phase will involve the application of various machine learning algorithms, such as regression analysis, neural networks, decision trees and others. By comparing the performance of these algorithms, we aim to identify the most effective techniques for predicting traffic flow and optimizing server usage.

Evaluation of the model's performance will be conducted using metrics such MAE, RMSE and MAPE. These metrics will help us benchmark the model's accuracy and reliability. We expect to achieve a high level of precision in our predictions, which will be validated through rigorous testing and cross-validation techniques.

Once the model is validated, we will deploy it in a simulated environment to assess its real-world applicability. We anticipate that the predictive model will demonstrate significant improvements in managing access control and resource allocation, leading to enhanced efficiency and reduced operational costs. The ability to dynamically adjust server capacity based on predicted traffic patterns will be a key finding, showcasing the model's scalability and practical value.

4. Discussion

Although the work is still ongoing, some preliminary conclusions can be outlined based on the steps taken so far and the expectations for the results.

Application of CRISP-DM: The CRISP-DM methodology has proven effective in organizing and structuring the project [21, 22]. The initial understanding of the business context and the definition of objectives provided a solid foundation for developing the predictive model.

Model Development: The modeling phase will involve applying various machine learning techniques. Experimenting with various types of machine learning algorithms allows us to identify the optimal solution, as different algorithms may excel under different conditions and data patterns. Comparing different algorithms will allow us to identify the best approaches to develop a dynamic system that supports various types of clients while simultaneously makes precise traffic flow predictions.

Expected Results: Although we are still in the development phase, we anticipate that the resulting predictive model will significantly improve access control management and resource allocation in port areas. By leveraging a range of machine learning techniques, we aim to create a robust, adaptive system that can respond to the fluctuating demands of different clients, ensuring high performance and reliability in managing the flow of people and goods in port areas. The ability to dynamically adjust server capacity based on predicted traffic patterns is one of the main expectations, demonstrating the scalability and practical value of the model.

Contributions to the NEXUS Agenda: We hope that this study will contribute significantly to the goals of the NEXUS Agenda, driving digital and sustainable transformation in the transport and logistics sector. Preliminary conclusions indicate that predictive modeling can optimize the efficiency and cost of port operations.

In conclusion, while the work is still in progress, the steps taken so far show promising directions and reaffirm the importance of predictive modeling in the context of access control in port facilities. We will continue to develop and validate the model, with the expectation of achieving results that provide practical and significant improvements for the sector.

Funding: Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).

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Simplifying Depot Management with the use of a Digital Twin

Rodolfo Santos, Laura Baeta and Hugo Fonseca

Devlop Lda: rodolfo.santos@devlop.systems; laura.baeta@devlop.systems; hugo.duarte.fonseca@devlop.systems

Abstract: The logistics and transportation industries face significant challenges in depot management due to fragmented and non-intuitive systems. This study introduces the Digital Depot Twin as a solution that combines 3D visualization, bidirectional data flow, and real-time notifications to streamline depot operations. The platform was developed through extensive research into existing solutions and employs Three.js for optimized 3D rendering and Azure Message Bus for controlled real-time updates. It integrates seamlessly with various Transport Management Systems (TMS) like Depot Systems, allowing for dynamic CRUD operations and data import from legacy systems via CSV uploads. Our testing confirmed the platform's capability to provide smooth visual performance and effective synchronization with TMS through APIs, facilitating real-time data updates between the 3D environment and TMS. Results indicate that the Digital Depot Twin enhances operational efficiency by allowing users to manage depot layouts, track historical data, and receive timely alerts in an intuitive interface. This approach not only simplifies complex tasks but also promotes more accurate and timely decision-making. The Digital Depot Twin thus represents a significant advancement in depot management, offering a scalable solution that adapts to the evolving needs of the logistics sector.

Keywords: Digital Twin, Depot Management, Three.js, Transportation Management Systems, Data Integration, Real-Time Synchronization, Operational Efficiency, 3D Visualization, Bidirectional Communication, User Interface Design.

1. Introduction

The logistics and transportation industries face challenges in efficient depot management due to fragmented systems and data silos. Existing solutions like FlexTerm, MaxWhere, and OPUS Terminal M, while functional, often lack real-time integration and interactive visualization, limiting their effectiveness in complex depot operations [6][7][5]. This research introduces one Digital Depot Twin, a unified 3D platform that enhances decision-making by enabling live data interactions and historical tracking within a spatial 3D interface [11][3]. The platform's aim for bidirectional communication with Transport Management Systems (TMS) is achieved through Azure Message Bus, which ensures synchronized data flow and efficient real-time updates [21][22]. Additionally, a notification system provides timely alerts, improving response times and operational awareness. The Digital Depot Twin offers an integrated approach that significantly advances depot management by addressing current technology gaps and meeting evolving industry demands [2][24].

2. Materials and Methods

The Digital Depot Twin 3D platform is designed for high performance, flexibility, and operational efficiency, providing a smooth and interactive 3D experience. Using

Three.js, the platform achieves a stable frame rate of 60 fps, ensuring users can navigate and interact with the 3D depot representation seamlessly, which is critical in real-time logistics [8][18]. The platform's adaptability enables depot operators to adjust layouts and operational elements, such as container positioning and loading zones, within the 3D space to match actual depot structures. This feature allows quick adjustments, aligning the virtual model with the physical environment [14].

For data synchronization, the platform aims to support bidirectional communication with various Transport Management Systems (TMS) via Azure Message Bus. Although, one of the constraints of this is the lack of endpoints on different TMS, the DepotSystems API, for example, receives only Gates Operations, Bookings and Accounts, this will limit the amount of information and representations that the Digital Twin can build [17]. This setup will allow real-time updates between the 3D interface and TMS, although slight delays may occur due to message queue processing [21][22]. The notification system built on Azure Message Bus provides timely alerts for critical operations like gate-ins, helping operators focus on high-priority tasks without overwhelming them with excessive notifications [16]. Additionally, the platform will record historical data, enhancing decision-making and enabling supervisors to monitor trends [24][26].

A good 3D mapping to define depot areas accurately is the final goal, converting real-world maps into a 3D matrix that maintains spatial authenticity will ensure realistic space allocation and it will allow easier updates as the depot layouts change, making the Digital Depot Twin a versatile and scalable solution.

3. Results

3.1. First Round of Performance Tests

Performance testing in WebGL, particularly using Three.js for 3D models, is essential for optimizing web-based applications. This test [27] assessed the impact of different model complexities, levels of detail, and browser compatibility to ensure consistent performance across environments. See Appendix A.

Tests ran on a 2020 MacBook Pro with an Intel Iris Plus Graphics card, across Google Chrome and Safari browsers. The environment included a skybox texture and a plane texture.

3.1.1. Metrics

- Cross-Browser Metrics:
  - FPS Count: An indirect FPS count was deduced by monitoring CPU usage, with an FPS counter later added.
  - Loading Time: Measured from page load until all models were displayed.
- Browser-Specific Metrics:
  - Chrome: Total Blocking Time (TBT) to evaluate rendering delays.
  - Safari: Energy Impact and CPU Usage to gauge battery impact and CPU demand.

3.1.2. Findings

- High-Polygon Models: Stable performance with 50x50 models, but significant lag and failures at 100x100 or 500x500 models.
- Mid-Polygon Models: Improved slightly, but 500x500 models still caused considerable lag.
- High-Polygon Reefer Model: Performed well up to 50x50 models but became sluggish at higher counts.
- 1000x1000 Models: Consistently failed to load in complex scenes, indicating the need for model and browser optimization.

3.1.3. Conclusion

High-poly models beyond 100x100 significantly degrade performance, with Safari showing more issues than Chrome. Achieving a smooth 3D experience will require optimizations in model complexity and rendering techniques. Future development should focus on efficient rendering, lower-poly models, and browser-specific optimizations.

3.2. 2nd Round of Performance Tests

The objective was to address limitations identified in the first test round by further reducing model complexity and using detailed UV maps to create surface textures [28].

The 3D environment remained the same, but the layout was simplified, and tests focused solely on Google Chrome. An FPS counter was added to enhance frame rate analysis.

Table 1. Table with the results of the 2nd round of performance tests performed on Google Chrome. Two columns, the left one for the 40DV container model and Reefer model. The number of containers progressively increases.

3.2.1. Findings

	40DV	Reefer
10x10	Loading Time: 1.69s Total Blocking Time: 0.0ms Frame Rate: Complete Frames FPS: ~60 FPS CPU Time: ~0.5ms — 1.9ms	Loading Time: 0s Total Blocking Time: 0.71ms Frame Rate: Complete Frames FPS: ~60 FPS CPU Time: ~1.04ms — 2.7ms
50x50	Loading Time: 1.64s Total Blocking Time: 329.30ms Frame Rate: Very Few Partially Incomplete Frames FPS: ~33-60 FPS CPU Time: ~11.8ms — 53.8ms	Loading Time: 1.67s Total Blocking Time: 0.0ms Frame Rate: Very Few Partially Incomplete Frames FPS: ~30-60 FPS CPU Time: ~9.7ms — 32.2ms
100x100	Loading Time: 12.41s Total Blocking Time: 17404.30ms Frame Rate: Some partial presented frame FPS: ~5-30 FPS CPU Time: ~35ms — 58.3ms	Loading Time: 1.2s Total Blocking Time: 1574.20ms Frame Rate: Some partial presented frame FPS: ~7-20 FPS CPU Time: ~38ms — 147.4ms
500x500	Loading Time: 12.41s Total Blocking Time: 42767.77ms Frame Rate: Several partially presented frames FPS: ~1FPS CPU Time: ~888ms — 1.2ms	Loading Time: 11.81s Total Blocking Time: 78245.13ms Frame Rate: Several partially presented frames FPS: ~0.9FPS CPU Time: ~1.2s — 7s
1000x1000	Doesn't Load	Doesn't Load

- Low-Detail Models: Despite reduced detail, performance did not improve significantly. The FPS still dropped substantially at 100x100 models and fell below 1 FPS at 500x500 models, causing interaction to become almost impossible.
- Positive Outcome: Loading times improved as models loaded nearly instantly, but the FPS remained problematic.
- Zooming Effects: FPS dropped significantly when zooming out, as more models needed rendering.

3.1.3. Conclusion

Reducing model detail lowered load times but did not address interaction lag at high model counts. This testing highlights the importance of efficient rendering techniques and possibly more drastic model simplifications to maintain a viable frame rate for large model counts. Further optimization, possibly at the rendering technique or system level, is required for a smoother user experience.

3.3. Dynamic 3D Visualization: Scissoring for Simultaneous Views

- To improve usability, we adopted a scissoring technique that enables both a main 3D view and an inset top-down view to be displayed on the screen at the same time. This dual-view setup enhances the user's experience by providing a comprehensive perspective of the scene.
- In this setup, two separate camera views are used: a main camera for navigating through the 3D scene and a second camera positioned above to capture an aerial, top-down view. The main view offers an immersive 3D experience where users can explore the scene, while the top-down inset provides spatial context from above, aiding orientation and navigation.
- The rendering process is designed to display these two views simultaneously. First, the main 3D view is rendered across the entire screen. Then, a defined area on the screen is sectioned off as an inset, where the top-down view is displayed. This inset view maintains synchronization with the main view, allowing both perspectives to remain consistent and responsive to user interactions.
- By implementing this scissoring technique, we achieved a cohesive visual layout that combines the benefits of detailed 3D interaction with an easily accessible overview, thus optimizing spatial awareness and ease of use within the 3D environment.

3.4. Seamless Operational Management: Automated Gate Processes with Real-Time Notifications

The Digital Depot Twin optimizes gate-in and gate-out processes by automating and reducing dependency on manual data entry, which previously burdened operators and introduced data entry errors. Now, when a container arrives at the gate, the system immediately notifies the operator, allowing the gate-in process to begin with a single click. This automation updates the system instantly, streamlining initial processing and minimizing manual steps.

Additionally, each container within the 3D environment is embedded with attributes imported from the Transportation Management System (TMS), such as container ID, load status, and destination. These preloaded properties ensure that much of the required information is auto-populated, accelerating container processing and improving data accuracy.

3.4. User-Centric Interface

Accessible and Intuitive Design: The interface is crafted for ease of use, allowing operators to quickly understand system functions with minimal training required.

Streamlined Gate-In/Out Modals: A single modal with 2-3 pages consolidates gate-in and gate-out processes, making it faster and more straightforward to navigate. See Image 1.

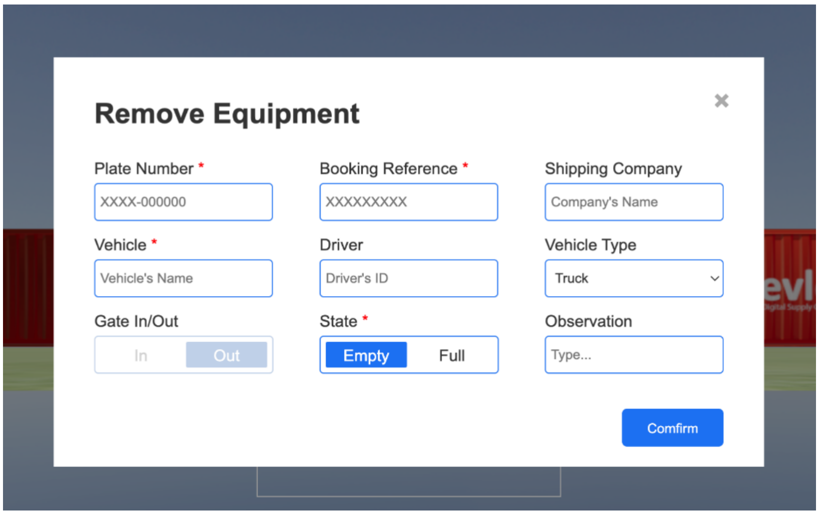

Figure 1. Gate-Out Modal

3D Environment Overview: Key containers and section details are visibly displayed in the left corner of the 3D environment, ensuring operators have immediate access to essential information. See Figure 2.

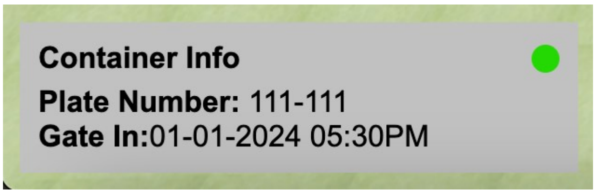

Figure 2. 3D Environment Overview

Right-Click Menu for Operations: Operators can easily access all operational functions and view the full history of any equipment through a right-click menu, enhancing workflow efficiency. See Figure 3.

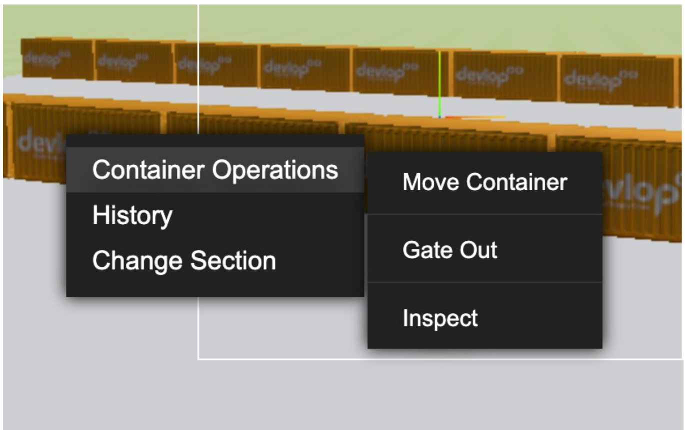

Figure 3. Right-Click Menu for Operations

Enhanced Notifications: Notifications include crucial information, like the container's plate number, and feature a "go to" button that instantly navigates the operator to the container's location in the 3D environment for immediate action. See Figure 4.

Quick Section Switching with Keybinds: Operators can effortlessly switch between sections and the depot using designated keybinds, simplifying navigation. Comprehensive Depot View: An overview of all depot sections allows users to click and directly access each section, providing a complete spatial awareness of the depot and improving operational fluidity.

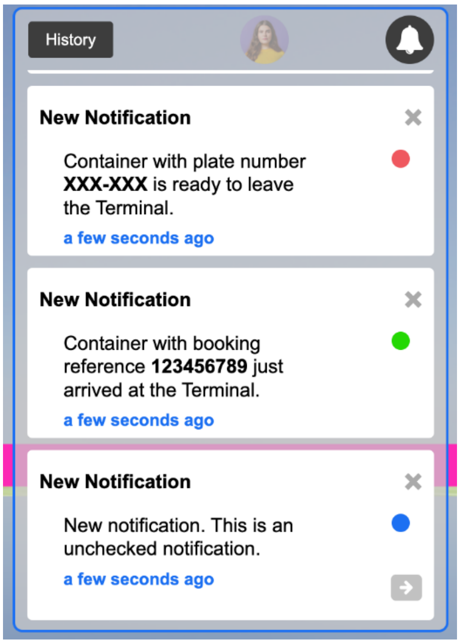

Figure 4. Enhanced Notifications

4. Discussion

The Digital Depot Twin offers a substantial advancement in depot management by addressing key limitations of existing tools like FlexTerm, MaxWhere, and OPUS Terminal M. These traditional solutions lack integrated real-time data and interactive 3D visualization [5][6][7], leading to inefficiencies and data silos. The Digital Depot Twin combines 3D visualization, bidirectional data flow, and a real-time notification system, creating a unified platform that improves decision-making and operational efficiency through immersive and interactive experiences [2][4][24].

Testing has demonstrated that the platform effectively transports users into an intuitive 3D environment where all features are accessible and easy to explore. Automated operations and streamlined menus help minimize errors, ensuring that critical information remains visible and readily available. The user-centric design, with features like a dual-view scissoring technique [29], quick-access menus, keybinds, and customizable options, promotes smooth navigation and operational efficiency. Furthermore, the platform's adaptability empowers depot managers to modify the 3D environment based on specific operational needs, accommodating depots that frequently expand or evolve.

Furthermore, the final goal of this Digital Depot Twin is to be built on digital twin technology by enabling real-time interactivity and synchronization with Transport Management Systems (TMS), enhancing operational transparency and data integrity. Future research will explore AI integration for predictive maintenance and the scalability of the platform for more complex logistics networks, potentially extending its impact across various deployment scenarios.

Author Contributions: The manuscript Conceptualization, Methodology, Software, Investigation, Data Curation, Writing the original Draft Preparation were done by Rodolfo Santos and Laura Baeta. Project Administration, Formal Analysis, Supervision, Reviewing and Visualization was done by Hugo Fonseca. Funding Acquisition and Resources were provided by DEVLOP.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.
Data Availability Statement: All the documentation regarding the results are available and were sent with this manuscript. The code from the prototype is not available because it is DEVLOP's intellectual property and protected by business confidentiality.

Acknowledgments: We appreciate all the support we got to write this manuscript as well as the liberty, time and resources provided by DEVLOP to this research and project. And we wanted to thank the NEXUS Board for this opportunity

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table 2. 1st Round of tests. 20DV container model. In Google Chrome.

	High Poly	**Mid Poly**
10x10	Loading Time: 8.12s Total Blocking Time (While Loading): 1340.46ms Total Blocking Time (While Interacting): 18.41ms Frame Rate: Complete Frames CPU Time: ~1.5ms — 4.4ms	Loading Time: 7.86s Total Blocking Time (While Loading): 9728.09ms Total Blocking Time (While Interacting): 0.0ms Frame Rate: Complete Frames CPU Time: ~0.9ms — 2.5ms
50x50	Loading Time: 8.94s Total Blocking Time (While Loading): 1340.46.ms Total Blocking Time (While Interacting): 1900.78ms Frame Rate: Some partial presented frame CPU Time: ~14.5ms — 46ms	Loading Time: 5.62s Total Blocking Time (While Loading): 4867.86ms Total Blocking Time (While Interacting): 0.0ms Frame Rate: Very few partial presented frames CPU Time: ~6.5ms — 12.0ms
100x100	Loading Time: 12.36s Total Blocking Time (While Loading): 1416.01.ms Total Blocking Time (While Interacting): 29544.92ms Frame Rate: Several partially presented frames CPU Time: ~84ms — 135ms	Loading Time: 6.47s Total Blocking Time (While Loading): 4895.97ms Total Blocking Time (While Interacting): 403.29ms Frame Rate: Some partial presented frame CPU Time: ~23.6ms — 42.2ms
500x500	Doesn't Lo ad	Loading Time: 17.88s Total Blocking Time (While Loading): 4662.40ms Total Blocking Time (While Interacting): 70552.92ms Frame Rate: Several partially presented frames CPU Time: ~760ms — 800ms
1000x1000	Doesn't Load	Doesn't Load

Table 3. 1st Round of tests. 40DV container model. In Google Chrome.

	High Poly	**Mid Poly**
10x10	Loading Time: 9.89s Total Blocking Time (While Loading): 1279.03ms Total Blocking Time (While Interacting): 22.18ms Frame Rate: Complete Frames CPU Time: ~1.5ms — 4.6ms	Loading Time: 4.11s Total Blocking Time (While Loading): 4591.67ms Total Blocking Time (While Interacting): 3424.87ms Frame Rate: Complete Frames CPU Time: ~0.97ms — 4.1ms
50x50	Loading Time: 10.91s Total Blocking Time (While Loading): 21618.27 ms Total Blocking Time (While Interacting): 280.46ms Frame Rate: Some partial presented frames CPU Time: ~21.5ms — 32.7ms	Loading Time: 6.56s Total Blocking Time (While Loading): 10912.72ms Total Blocking Time (While Interacting): 0.0ms Frame Rate: Very few partial presented frames CPU Time: ~6.2ms — 22.9ms
100x100	Loading Time: 12.76s Total Blocking Time (While Loading): 2215.03ms Total Blocking Time (While Interacting): 18899.76ms Frame Rate: Several partially presented frames CPU Time: ~79ms — 152ms	Loading Time: 6.92s Total Blocking Time (While Loading): 1444.11ms Total Blocking Time (While Interacting): 5122.34ms Frame Rate: Some partial presented frames CPU Time: ~28.3ms — 73ms
500x500	Doesn't Load	Loading Time: 16.46s Total Blocking Time (While Loading): 119ms Total Blocking Time (While Interacting): 56876.92ms Frame Rate: Several partially presented frames CPU Time: ~760ms — 1s
1000x1000	**Doesn't Load**	**Doesn't Load**

Table 4. 1st Round of tests. Reefer model. In Google Chrome.

	Mid Poly
10x10	Loading Time: 15.33s Total Blocking Time (While Loading): 1298.02ms Total Blocking Time (While Interacting): 0.0ms Frame Rate: Very few partial presented frames and dropped frames CPU Time: ~2.6ms — 6.6ms
50x50	Loading Time: 14.04s Total Blocking Time (While Loading): 2445.59ms Total Blocking Time (While Interacting): 8731.74ms Frame Rate: Several partially presented frames and a few dropped frames CPU Time: ~42ms — 222ms
100x100	Loading Time: 15.16s Total Blocking Time (While Loading): 1295.37ms

	Mid Poly
	Total Blocking Time (While Interacting): 29543.09ms Frame Rate: Several partially presented frames CPU Time: ~163ms — 1s
500x500	Doesn't Load
1000x1000	Doesn't Load

Table 5. 1st Round of tests. 20DV container model. In Safari.

	High Poly	**Mid Poly**
10x10	Loading Time: 6.47s CPU Usage: High Average: 39.0% Highest: 66.4%	Loading Time: 4.39s CPU Usage: Medium Average: 16.3% Highest: 41.9%
50x50	Loading Time: 8.58s CPU Usage: High Average: 91.0% Highest: 120.0%	Loading Time: 3.83s CPU Usage: High Average: 91.2% Highest: 129.7%
100x100	Loading Time: 12.83s CPU Usage: Very High Average: 101.5% Highest: 163.0%	Loading Time: 4.89s CPU Usage: High Average: 96.4% Highest: 133.1%
500x500	Doesn't Load	Loading Time: 15.17s CPU Usage: Very High Average: 110.9% Highest: 383.3% Crashed
1000x1000	Doesn't Load	Doesn't Load

Table 6. 1st Round of tests. 40DV container model. In Safari**.**

	High Poly	Mid Poly
10x10	Loading Time: 9.07s CPU Usage: High Average: 31.4% Highest: 46.6%	Loading Time: 5.08s CPU Usage: Medium Average: 12.3% Highest: 33.3%
50x50	Loading Time: 9.32s CPU Usage: High Average: 93.2% Highest: 143.4%	Loading Time: 4.63s CPU Usage: High Average: 59.5% Highest: 115.3%
100x100	Loading Time: 10.32s CPU Usage: High Average: 99.1% Highest: 204.3%	Loading Time: 5.63s CPU Usage: High Average: 94.2% Highest: 147.9%
500x500	Doesn't Load	Unable to Interact
1000x1000	Doesn't Load	Doesn't Load

Table 7. 1st Round of tests. Reefer model. In Safari.

	High Poly
10x10	Loading Time: 10.03s CPU Usage: High Average: 95.7% Highest: 122.1%
50x50	Unable to Interact
100x100	Unable to Interact
500x500	Doesn't Load
1000x1000	Doesn't Load

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Exploring the use of Digital Twins to optimize berth processes in Commercial Ports

Henrique Calhau, Jacinto Estima and Alberto Cardoso

University of Coimbra, CISUC, Department of Informatics Engineering;
calhau@student.dei.uc.pt; estima@dei.uc.pt; alberto@dei.uc.pt

Abstract: Maritime Ports are sophisticated logistic centers that enable the transportation of goods through sea routes, playing a crucial role in global trade and supply chain coordination. They include tasks like loading and unloading cargo, mooring ships, and allocating resources. Digital Twins (DTs) are simulated models mirroring physical systems, allowing for immediate monitoring, simulation, and enhancement. Commercial Ports are striving for innovative technological solutions to cope with the ever-increasing growth of transport, while at the same time improving their environmental footprint. Although DTs have been successfully integrated in some industries, there is still a lack of cross-domain understanding of what constitutes a DT. Furthermore, the implementation of the DT in complex systems such as the port is still in its infancy. This work aims to fill this gap by building a 2D DT prototype for ports, laying the groundwork for more advanced systems in the future. The developed system includes various features, including the ability to perform visual simulations of berthing and mooring procedures, the integration of Machine Learning (ML) techniques for precise prediction of vessel arrival times, and the capability to compare different berth plans. A DT prototype with these capabilities will help in advancing in the development of more extensive and robust DT systems, aiding in the optimization of port operations as well as improving their energy efficiency.

Keywords: digital twin; port; berth; vessel; machine learning; industry 4.0; internet of things; artificial intelligence.

1. Introduction

The concept of Digital Twin (DT) has been addressed several times given its real application advantages in different scenarios. Authors have attempted and continue to search for ways to better define DT, as knowledge about it increases and questions that still exist become more transparent. One of the first approaches of the DT concept was made in 2002 by the factoring scientist Michael Grieves, in a presentation regarding Product Lifecycle Management in industry. Grieves defines the DT as a collection of virtual information structures that comprehensively represent a physical product, whether it is in the conceptual or material form, comprising its smallest atomic details to its larger geometric aspects. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its DT [1]. In 2012, NASA proposed a widely accepted definition of DT, stating that a DT is a comprehensive simulation of a complex product. It incorporates multiple physics and scales, and utilizes the most accurate physical model, real-time sensor data, historical data, and other relevant information to accurately replicate the behavior and characteristics of its corresponding twin [2]. Figure 1 presents a timeline of some of the most important events regarding the evolution of DTs.

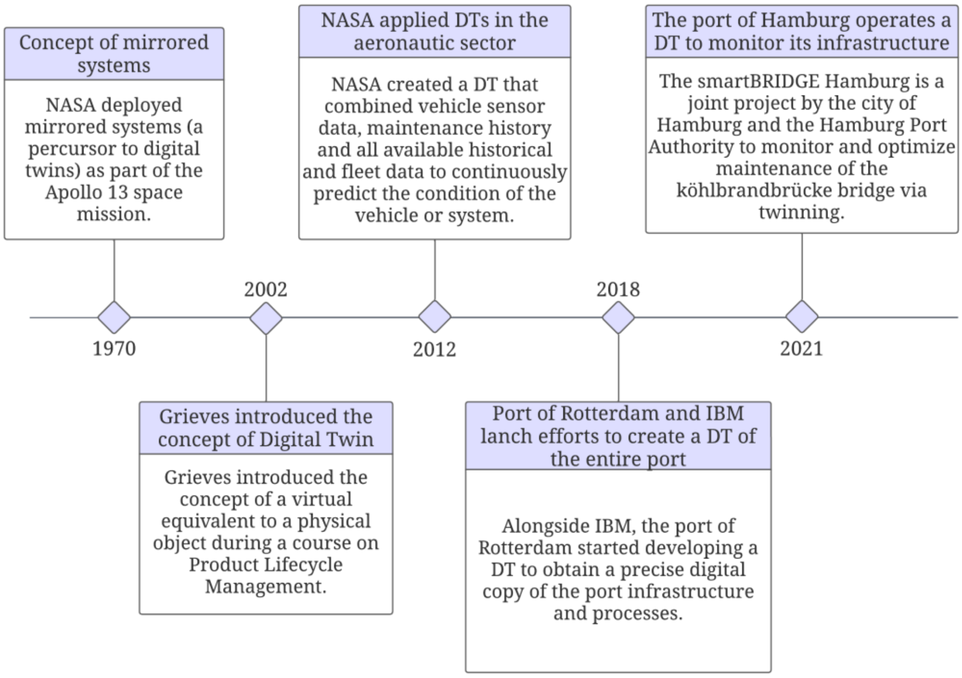


Figure 1. Timeline of historic DT events (adapted from [3]).

A DT contributes to improving processes along the entire value chain, allowing different stages to be seamlessly integrated using a virtual representation of a product or process. This multi-platform technology is built on a significant layer of powerful software and hardware that can include a simulation model, IoT sensors, data analytics and Artificial Intelligence (AI), human-machine interface, Virtual Reality (VR) and/or Augmented Reality (AR), and 3D computer-assisted design [4]. Connecting the physical and virtual via DTs allows improvements in domains such as performance, security, decision-making, risk assessment, time and process optimization [5]. On the other hand, some of the main concerns are related to costs, privacy, integration, reliability and maturity [3, 4]. Although different authors have different views about the properties of a DT and its components, a DT has at least three parts: the physical world, the virtual world, and the bidirectional connection to share data between them [5]. For example, one DT reference architecture model proposed by [7] has four parts: physical, digital, cyber, and communication for data exchange between the three layers. The physical layer defines real attributes, involving objects, assets, products, personnel, equipment, facilities, systems, processes, and surroundings, with sensors and actuators as crucial components. The digital layer collects data in multiple formats, providing digital duplicates of physical entities, while the cyber layer combines cloud processing and storage for a dynamic data model, using scalable technologies.

One industry that can benefit from this type of technology is the Maritime Industry. With the steady growth of maritime transport and global sustainability efforts, ports are under increasing pressure to improve their profitability, environmental friendliness, energy performance and efficiency. Commercial ports fulfil a range of services, as nodes in transportation chains and hubs of economic operations connected to the handling of ships and cargo in the port. As ports handle a multitude of processes performed by a variety of actors in parallel, it is increasingly important to improve the overall view of port processes and identify potential bottlenecks to increase efficiency, safety, and sustainability throughout the port ecosystem [3]. Large ports that have busy container terminals have redefined the container logistic processes and operations through the adoption of different digital technologies such as AI, Blockchain, Cloud Computing, IoT and DTs [8]. Table 1 illustrates multiple examples of important ports adopting DTs for different purposes.

Table 1. Summary of the application of the DT in each port (adapted from [9]).

Location	DT application
Rotterdam, Netherlands	Infrastructure and traffic management
Livorno, Italy	Infrastructure and traffic management
Qingdao, China	Equipment and terminal management and overall optimization
Busan, South Korea	Traffic management
Hamburg, Germany	Infrastructure and traffic management

2. Materials and Methods

Design Science Research Methodology (DSRM) was the approach used in the design and creation of this artifact. This methodology comprises six steps: Problem identification and motivation; Definition of the objectives for a solution; Design and development; Demonstration; Evaluation; Communication [10]. This process can (and should) be iterative. Figure 2 intends to demonstrate how the objectives and the design and development phases can be iteratively returned to and adjusted following the evaluation and/or communication.

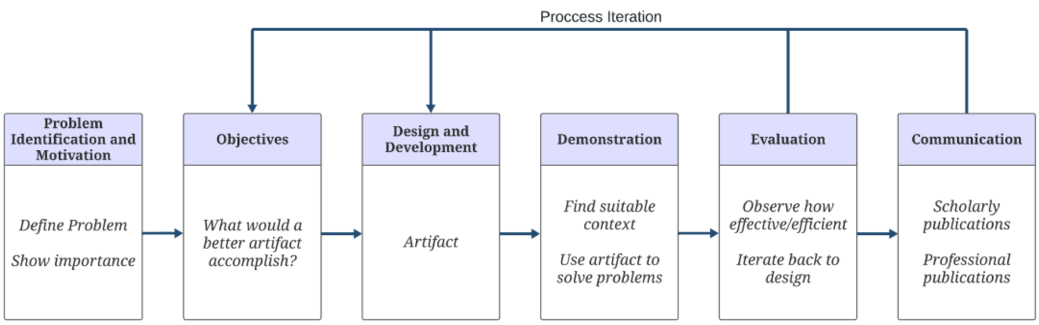


Figure 2. DSRM diagram (adapted from [10]).

The problem is identified, while the Maritime Industry continues to grow and ports are under increasing pressure to improve their efficiency, profitability and sustainability, there is still a lack of innovative solutions for optimization and visualization of port operations. The main objectives of this prototype consist in enabling the user to create, visualize, simulate and compare different berth plans. To meet these objectives, three different components were defined: (i) a 2D Unity environment that allows the user to visualize the port, simulate ships berthing operations and compare different plans; (ii) a Flask API that incorporates an interface and handles the ML models in order to create new berth plans; (iii) a Firebase Realtime Database that allows the user to store the generated berth plans and the details about each performed simulation.

The berth plans are generated using ML models which anticipate the arrival times of vessels and optimize their berth. This is possible through the integration of the ML work performed by Afonso Matoso Magalhães [11]. By creating an interface, the user can input different sets of data to generate different berth plans. These plans can then be visualized and compared within a 2D Unity-based application. The created berth plans and the data related to the simulations are stored in a database for later use. The resulting architecture of this artifact can be seen in Figure 3.

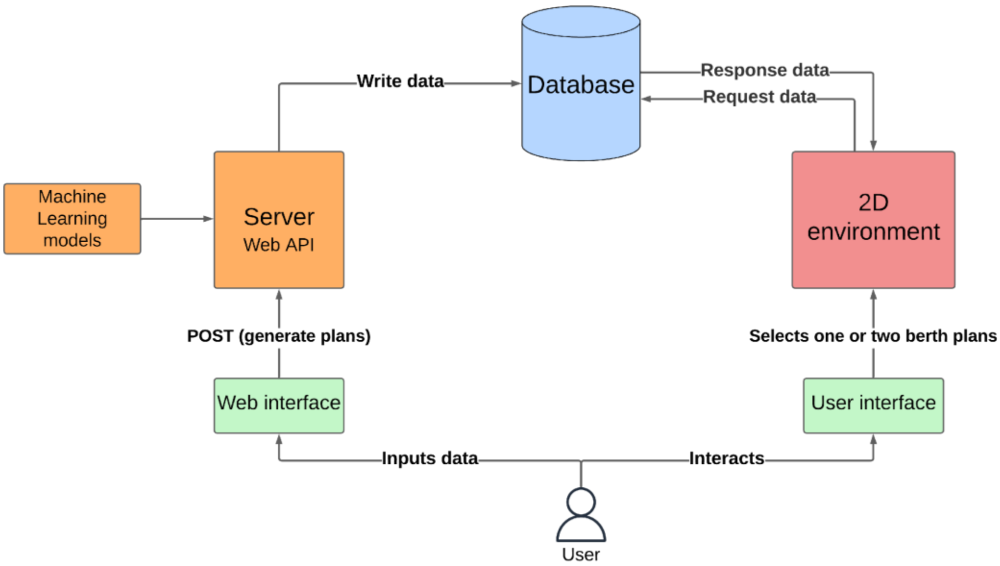


Figure 3. Architecture diagram.

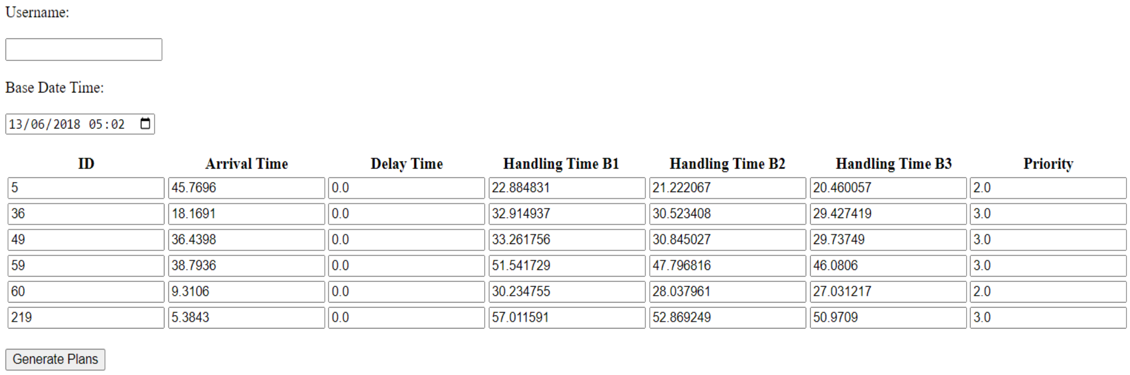
3. Results

The resulting solution includes ML integration, real-time data processing, and interactive simulation environments to create a functional tool for optimizing port operations. The primary proposed functionalities for this artifact were achieved:

- Integration of ML models for berth plan generation;
- Creation of a 2D simulation environment;
- Database integration for efficient data storage and management;
- Demonstration of the prototype's capabilities in simulating various scenarios and comparing berth plans.

3.1. Server API

In the server API, the user has the option to input different sets of data and generate new berth plans using the ML models (Figure 4).


Username:

Base Date Time:

13/06/2018 05:02

ID	Arrival Time	Delay Time	Handling Time B1	Handling Time B2	Handling Time B3	Priority
5	45.7696	0.0	22.884831	21.222067	20.460057	2.0
36	18.1691	0.0	32.914937	30.523408	29.427419	3.0
49	36.4398	0.0	33.261756	30.845027	29.73749	3.0
59	38.7936	0.0	51.541729	47.796816	46.0806	3.0
60	9.3106	0.0	30.234755	28.037961	27.031217	2.0
219	5.3843	0.0	57.011591	52.869249	50.9709	3.0

Generate Plans

Figure 4. Flask API Web interface.

3.2. 2D environment (Unity)

In Unity, if the user selects only one plan, the simulation begins, allowing for the visualization of vessel movement and berthing in the port (Figure 5).

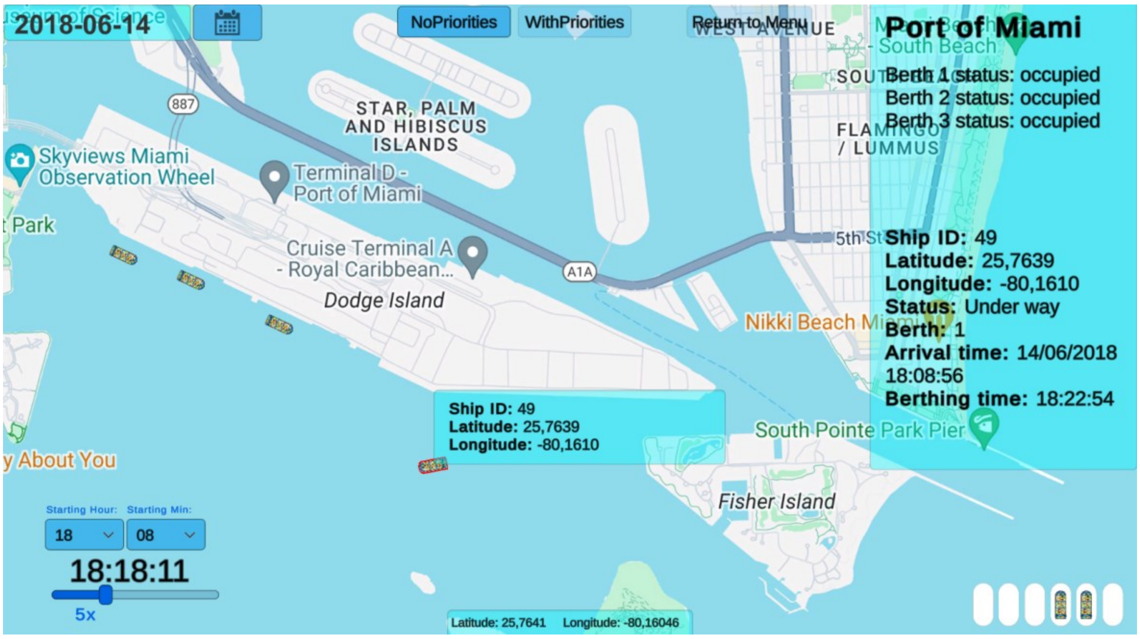


Figure 5. User chooses one berth plan.

If the user chooses two berth plans, a visual comparison of the two plans is displayed including relevant information about each plan (Figure 6).

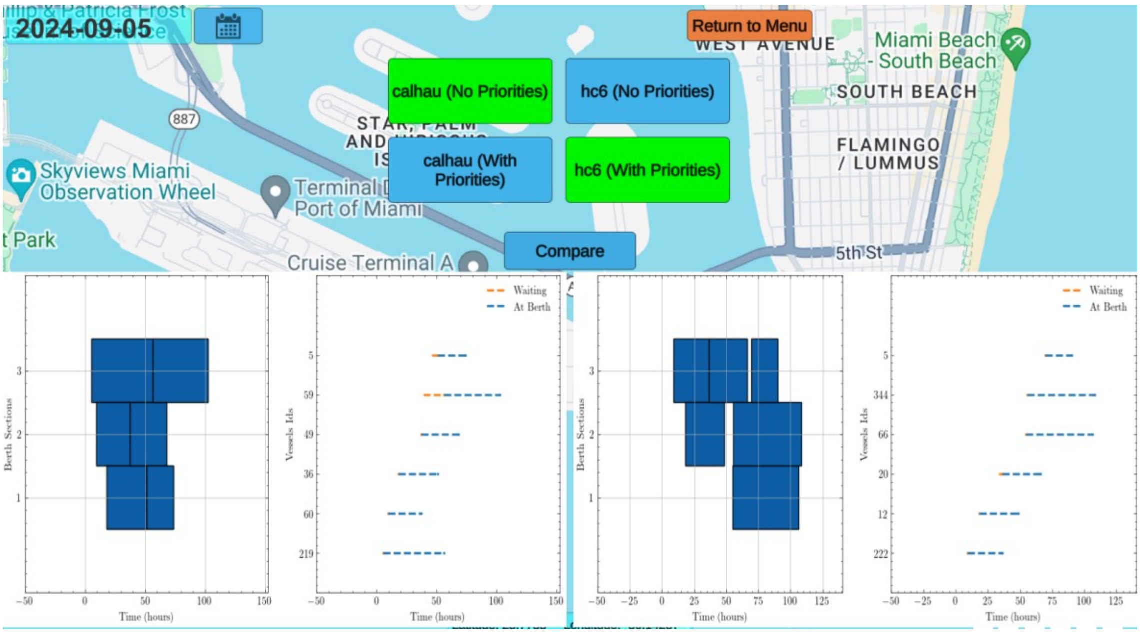


Figure 6. User chooses two berth plans.

4. Discussion

After the development of this artifact, the evaluation was done by conducting a demo with representatives from ESRI, an important stakeholder from the NEXUS program. The demonstration was supported by a series of questions, to get the most valuable feedback and assess the quality of the artifact. Overall, the feedback received was very positive. The participants recognized the value of berth simulation and comparison, as well as the importance of creating new berth plans to optimize berth planning for the possibility of delays.

This research successfully developed a DT prototype designed for the Maritime Industry, specifically addressing the challenges of berth planning in maritime ports. By integrating Machine Learning models with a 2D Unity environment and a robust database, the prototype enables the simulation, comparison, and optimization of different berth plans. The positive feedback from industry experts validates the potential of this solution to enhance port efficiency and decision-making. Future research could explore the integration of additional maritime factors, such as weather conditions and AIS data, to further refine the simulation capabilities. Moreover, expanding the prototype to a 3D environment and incorporating real-time data could significantly enhance its practical application and impact on port operations. While the prototype demonstrates promising results, further development and testing are necessary to fully realize its potential benefits.

Author Contributions: Conceptualization, H.C., J.E. and A.C.; methodology, H.C., J.E. and A.C.; software, H.C.; validation, J.E. and A.C.; formal analysis, J.E. and A.C.; investigation, H.C.; writing—original draft preparation, H.C.; writing—review and editing, H.C., J.E. and A.C.; visualization, H.C.; supervision, J.E. and A.C.; project administration, J.E. and A.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Project "Agenda Mobilizadora Sines Nexus". ref. No. 7113, supported by the Recovery and Resilience Plan (PRR) and by the European Funds Next Generation EU, following Notice No. 02/C05-i01/2022, Component 5 - Capitalization and Business Innovation - Mobilizing Agendas for Business Innovation. It was also funded through national funds by FCT

- Fundação para a Ciência e a Tecnologia, I.P., in the framework of the Project UIDB/00326/2020 and UIDP/00326/2020.

Institutional Review Board Statement: Not Applicable

Informed Consent Statement: Not Applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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Smart Impact Management of KPIs on Maritime Ports

Ângela F. Brochado [1,3], Lara Esteves [2] and Eugénio M. Rocha [2,3*]

[1] Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), University of Aveiro, 4 - 3810-193 Aveiro, Portugal
[2] Department of Mathematics (DMat), University of Aveiro, 3810-193 Aveiro, Portugal 6
[3] Center for Research and Development in Mathematics and Applications (CIDMA), University of Aveiro, 3810-193 7 Aveiro, Portugal
* Correspondence: eugenio@ua.pt

Abstract: Seaport digitization and advanced dlonata analysis enhance transparency, efficiency, and decision-making through relevant key performance indicators (KPIs). This work proposes a solution with two components: an optimization algorithm and a dynamic web application for data analysis and interaction. The algorithm focuses on key seaport performance areas, including governance, human resources, finance, resilience, operations, and environmental sustainability, generating recommendations for impactful variable changes. The interface offers time series visualization, basic statistical data, and a scenario analysis tool with practical constraints. This tool aids seaport stakeholders in making informed decisions, identifying improvements, streamlining processes, reducing costs, increasing efficiency, and enabling strategic planning for sustainable operations. Initially developed under the Portuguese NEXUS Agenda, the application is adaptable for any port entity worldwide due to its standardized KPI framework.

Keywords: key-performance indicators, seaport management, optimization

1. Introduction

Digitization and data analytics tools have been highly regarded research topics in many industries worldwide, and seaports management has been no exception. In the case of Portuguese Port of Sines, the first steps towards digitization were made in January 2003 [2], and some years later, in October 2020, the *Janela Única Logística* (JUL) started its implementation. JUL embraces all the Port of Sines' supply chain stakeholders, integrating land, road, and rail transport, including connections to dry ports and logistics platforms [3]. It also enables the tracing and tracking of the cargo to final destinations, thus raising the standards of efficiency, reliability and transparency of the service provided [2]. Studying and analyzing all these data is not a trivial task and it represents a great challenge for performance evaluation in the port.

To evaluate the performance of a product, process, individual or other, it is necessary to define, measure and monitor a series of key performance indicators (KPIs). Consequently, KPI determination, analysis, and improvement is key as it facilitates the assessment of ports and terminals in accordance with pre-established criteria, tailored to the specific requirements of the involved stakeholders [6].

One of the major tasks of top managers is to improve KPIs, which is challenging due to several factors, between them we have:

- (F1) Setting relevant KPIs that align with the port goals is crucial but often difficult, as it requires a balance between quantitative and qualitative metrics. Effective monitoring and continuous adjustment of KPIs are necessary but often challenging to implement consistently;

- (F2) Data quality and availability issues, such as inaccurate data and fragmented data sources, complicate the measurement and tracking of KPIs;
- (F3) Resource constraints, including limited budgets and competing priorities, further complicate efforts to improve KPIs;
- (F4) Organizational culture also plays a significant role, with resistance to change and lack of buy-in from employees and leadership hindering progress;
- (F5) The complexity of measuring certain KPIs and the time lag in seeing results can make it hard to assess the impact of changes promptly. Also, the set of improvement actions that can be taken, in a fixed period, is limited and so determining the variables and degree of change that has more impact is of major importance.

In this work, we propose two components: an innovative optimization algorithm (based on variables, KPI, dimensions, metrics, and scenarios), and a dynamic web application to show the data and to interact with the algorithm. The aim is to give a strong solution to the issues in factors F1 and F5, and address F3. This approach not only improves management results but also enhances credibility and trust among international stakeholders, including shipping companies, investors, and regulatory bodies. It aids port authorities and operators in making informed decisions, identifying areas for improvement, streamlining processes, reducing costs, increasing operational efficiency, and enabling strategic planning.

2. Material and methods

Factor F1 relates to the choice of relevant KPIs. A KPI should adhere to the SMART criteria: it must have a Specific purpose for the business, be Measurable to obtain a value for the KPI, be defined in accordance with Achievable norms, be Relevant to the success of the organization, and be Time-phased, demonstrating the value/outcomes for a predefined and relevant period [7].

For seaport performance measurement, we propose to follow the proposal of the United Nations, which in 2023 developed a standardized framework [1] that offers significant benefits for benchmarking and comparison across different ports worldwide. The document provides an exhaustive description of relevant KPIs in the following dimensions:

- **Human resources**: these KPIs focus on the development of human capital, i.e., they measure and evaluate the performance and efficiency of an organization's human talent. They have been classified into four different categories: equal opportunities indicators, job quality indicators, social wellbeing indicators and productivity indicators.
- **Finance**: financial KPIs are useful for analyzing an organization's financial health and performance, allowing us to understand the economic impact of decisions made by port authorities. They have also been classified into four categories: accounting indicators, port activity indicators, financial capacity and investment indicators and financial performance indicators.
- **Resilience**: the assessment of maritime resilience indicators is concerned with the capacity of maritime infrastructure systems to withstand, adapt to and recover from disturbances, crises or adverse events. A port may be deemed resilient when it can maintain essential services in the face of internal and external shocks. The KPIs have been classified into two distinct categories: physical security indicators and cyber security indicators.
- **Vessel operations**: KPIs on vessel operations are a way to evaluate the efficacy and efficiency of port operations regarding the movement and management of vessels.

The KPIs are divided into two categories: time indicators and vessel characteristics indicators.

- **Cargo operations**: cargo operations KPIs evaluate the efficacy, productivity and efficiency of the loading and unloading processes in ports and terminals. They are of paramount importance, given that as the size of vessels increases, so does the competitiveness and capital intensity of port investment. These KPIs can be classified into three categories: operational performance, service level and utilization.
- **Environmental sustainability**: environmental sustainability KPIs help assess a port's environmental impact, evaluate the effectiveness of operational controls, and determine if environmental management practices are achieving optimal performance. These KPIs are categorized into seven groups: climate change indicators, port activity emissions, resource consumption, waste production, port development, biodiversity impact, and environmental management indicators.

In the above classes, each KPIs were designed to allow seaports to align with the Sustainable Development Goals (SDGs), improving their public image and compliance with international regulations [8].

In this work, the basic data entities are time series. A variable is a time series representing a physical process. A KPI is a well-defined mathematical expression that composes variables into a new time series, typically in the form of a ratio between variables. A dimension encompasses one or more KPIs, typically through the weighted sum of the set of KPIs within the scope of the performance dimension. The authors also propose a fourth entity class called a metric, which consists of a measure of error/distance that makes it possible to compare and evaluate performances, e.g., between different companies, according to the same dimensions.

For clarification, the following practical example is used. Let V1, V2, V3 and V4 be a set of variables from a dataset on container handling operations at the Port of Sines, in 2023:

$$V1 = number\ of\ containers\ handled\ at\ quay\ 1$$

$$V2 = number\ of\ containers\ for\ handling\ on\ quay\ 1$$

$$V3 = energy\ consumption\ from\ cranes\ in\ quay\ 1$$

$$V4 = renewable\ energy\ consumption\ from\ cranes\ in\ quay\ 1$$

Based on these variables, the following KPIs can be calculated for 2023:

$$KPI1\ (2023) = overall\ container\ throughput\ of\ quay\ 1\ in\ 2023$$

$$KPI1\ (2023) = \frac{\sum_{year=2023}(V1)}{\sum_{year=2023}(V2)},$$

$$KPI2\ (2023) = energy\ consumption\ at\ quay\ 1\ in\ 2023$$

$$KPI2\ (2023) = \frac{\sum_{year=2023}(V3)}{\sum_{year=2023}(V1)},$$

$$KPI3\ (2023) = energy\ consumption\ \%\ from\ renewable\ sources\ at\ quay\ 1\ in\ 2023$$

$$KPI3\ (2023) = \frac{\sum_{year=2023}(V4)}{\sum_{year=2023}(V3)} * 100\ .$$

Notice that KPIs may compete, for example, increasing variable V1 will translate into an increase of KPI1 but a decrease of KPI2.

Then, based on these KPIs, the next level of performance analysis follows, by dimension. For the dimension of "environmental sustainability" (a reduced version of the one proposed by UN2023), KPI2 and KPI3 are included. In practical terms, it can be expressed as:

$$Dim_{\text{environmental sustainability } of \ 2023} = 50\% * KPI2 + 50\% * KPI3$$

Finally, a possible metric which represents an error measure of the previous dimension is given by:

$$Metric_{Dim_{\text{environmental sustainability}}} =$$

$$Dim_{\text{environmental sustainability } goal} - Dim_{\text{environmental sustainability } of \ 2023}$$

We also introduce the notion of scenarios, which are parametric transformations of variables and a set of constraints. The algorithm will determine the best parameters for a given set of variables, KPIs, dimensions, metrics, and one scenario. The parameters measure, in some sense, the effort a manager needs to execute to attain a new variable value, which by itself automatically influences KPIs, dimensions, and measures. Examples of scenarios are:

- **Historical**: The effort is optimized for time series of the same institution (port/department) but over different periods of time.
- **Competition**: The effort is optimized considering differences between the current institution and data from a competitor.
- **Inertia**: The effort is optimized considering that, without exerting any effort, the system has a high probability of moving the KPIs to some stationary points.

3. Main results

To implement the methodology, a smart impact management of KPIs (SIMK) tool was developed, composed of the optimization algorithm, as an API service, and a user interface, as a Web App. In Figure 1, the global use of SIMK is presented. Data is obtained from JUL platform or from a data simulator. In each instant of time, a decision-maker analysis is executed, generating recommendations regarding which variables should be changed to achieve the highest impact on KPIs. In the next instant of time, besides making a new analysis, the system also can benchmark the effectiveness of the actions made by the manager and learn which have further impact.

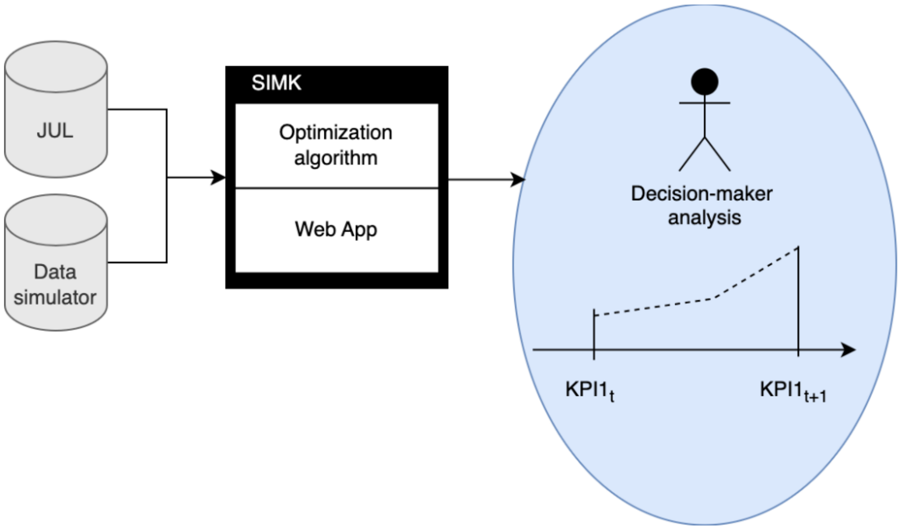

Figure 1: General scheme about the decision-making stage.

Figure 2 details the data flow from reception to decision-making. "Data reception" marks the initial point of data entry, while "data storage" involves storing this data. In the "data processing" stage, data is pre-processed for subsequent "data analysis," where statistical metrics are evaluated. During visualization, suitable graphics are created. The "Smart KPI App" allows stakeholders to interact with the data in two ways: "Consult metrics values" for basic statistics, histograms, boxplots, and variable evolution graphs, and "Scenarios analysis" for simulating variable impacts on KPIs. In the decision-making stage, stakeholders use this information to make informed decisions. A "Feedback loop" allows participants to provide feedback on decisions, which informs and repeats the decision-making process to assess changes' effectiveness.

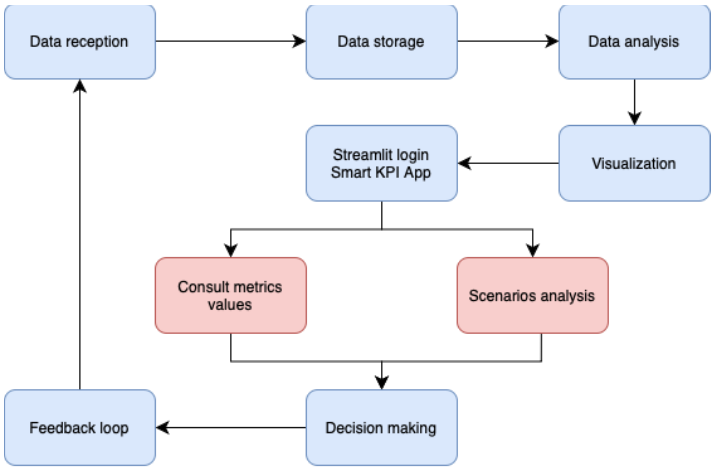

Figure 2: Data flow illustration from the data reception to the decision-making stage

Decision-makers can use an optimization tool for exploratory analysis of variable variations and their impact on KPIs, dimensions, and error metrics. By adjusting the effort rate (λ), different performance scenarios can be explored, though practical restrictions limit the extent of these adjustments based on company capacity. Due to incomplete KPI data from the Port of Sines, an Event-Driven Data Simulator using the Python module Salabim was developed to generate variables and KPIs under various conditions, including catastrophic events and normal operations. Simulations showed an average improvement of over 10% in metrics when using SIMK. Full validation of the tool requires complete data from the Port of Sines. Using real data, significant improvements in financial performance, cargo operations, and environmental sustainability metrics are anticipated. This tool aims to optimize KPIs efficiently, reflecting essential considerations for port performance and competitiveness.

4. Conclusions

This work introduced an optimization algorithm and a dynamic application incorporating the standardized seaport management KPIs, proposed by the United Nations in 2023. Integrating these performance metrics enhances general operational indicators but also the credibility and trust among international stakeholders, including shipping companies, investors, and regulatory bodies. It was designed to assist Portuguese Port of Sines authorities in making informed decisions, identifying areas for improvement, and enabling strategic planning, paving the way towards sustainable operations according to the SDGs.

The interface features visualization of critical logistics variables, access to basic statistical data, and generation of evolutive charts. Additionally, it includes a novel scenario analysis tool to evaluate the impact of variables on KPIs and generate a set of recommendations with the best actions to be implemented.

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Towards an Automated Visualisation Recommendation System for Open Data Platforms

Duarte Menezes, João Macedo, João Correia * and Evgheni Polisciuc

University of Coimbra, CISUC/LASI, DEI; duarte.emanuel.meneses@gmail.com; jncor@dei.uc.pt; evgheni@dei.uc.pt
*Correspondence: jncor@dei.uc.pt

Abstract: The exponential growth of data in the digital age necessitates efficient tools for data management and analysis. Open Data platforms are crucial for large-scale businesses, enhancing decision-making through neutrality and data-sharing. However, the vast data available poses significant analysis challenges, requiring advanced visualisation techniques. This study presents an innovative AI-driven system that recommends data visualisations automatically, making analysis more accessible and efficient. The system includes three main components: feature selection, visualisation generation, and a user-friendly interface, all designed to streamline the visualisation process and support informed decision-making. Machine learning techniques preprocess data, identify key features, and detect outliers, ensuring meaningful insights. The approach uses an ensemble of algorithms for correlation and outlier detection and employs the DeepEye tool for visualisation generation. Initial implementations with data from the NEXUS project at Porto de Sines show the system's effectiveness, providing valuable logistics insights. The results indicate that the system facilitates quicker access to data insights and reduces the technical expertise required for data analysis.

1. Introduction

The modern digital landscape has led to an increase in data generation, significantly impacting how businesses and societies operate. This surge in data production, driven by advancements in technology and connectivity, has increased the demand for the development of tools that can effectively manage and analyse large amounts of information. Open Data platforms have emerged as critical assets in this context, providing the infrastructure needed to handle complex processes through ecosystem neutrality and enhanced data-sharing capabilities [1]. These platforms empower users to access, analyse, and derive insights from datasets, enabling informed decision-making and fostering business intelligence. A prime example of the application of Open Data platforms is observed at Porto de Sines, where the NEXUS project is providing a digital transformation of logistics operations of the port. By creating an open data platform, Porto de Sines aims to streamline its logistics processes, enhancing efficiency and effectiveness. However, the extensive volume of data generated poses a significant challenge to analysis, showcasing the need for visualisation techniques for analytics. Visualisation not only aids in understanding complex datasets but also facilitates the exploration of data patterns, correlations, and outliers [3].

2. Materials and Methods

The complex datasets also facilitate the exploration of data patterns, correlations, and outliers [3] .The proposed automated visualisation recommendation system comprises three main components: feature selection, visualisation generation, and a user-friendly graphical user interface (GUI). The system's modular design ensures that each component can be independently improved, facilitating adaptability and continuous enhancement (check Figure 1. for an overview).

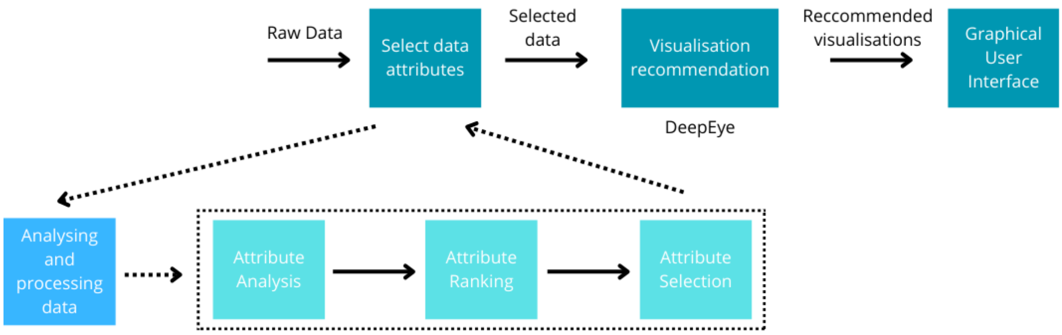

Figure 1. Overview of the methodology employed for the automatic visualization recommendation.

Data Preprocessing: This process begins with an analysis of missing values (NaNs) and the application of a Label Encoder to manage categorical variables. Features with more than 80% NaN values are excluded, and rows with residual NaNs are removed from further analysis. Encoding non-numerical values is crucial since subsequent algorithms require numerical inputs.

Feature Selection for Visualisation: The system targets two primary objectives for visualisation: detecting correlations and identifying outliers. Given the diverse nature of data on open data platforms, an ensemble of algorithms is employed to select features for correlation analysis. Pearson, Kendall's Tau, and Point-biserial correlations are calculated for feature pairs, retaining only those with correlations in a predetermined and configurable interval. The ensemble ensures that only correlations recognized by at least two algorithms are deemed significant.

Outlier Detection: For univariable outliers, the Z-score method with a configurable threshold is utilized. For multivariable analysis, linear regression is applied to assess variable dependency. An ensemble of algorithms, including Isolation Forest, Local Outlier Factor, One-Class SVM, and KNN, detects outliers in dependent variable pairs. Only points detected by at least two ensemble algorithms are considered outliers.

Visualisation Generation: Following feature and outlier selection, the DeepEye [2] tool is employed to generate visualisations. DeepEye supports popular visualisation types such as bar, line, pie, and scatter plots, alongside data transformations like binning, grouping, aggregation (SUM, AVG, COUNT), and ordering. The tool generates HTML visualisations rendered in PyeCharts, facilitating integration into our React-based GUI. The GUI provides an intuitive platform for data analysis, displaying visualisations and data tables simultaneously for comprehensive analysis.

Despite the critical role of data visualisation, the scarcity of skilled data professionals and the fast-paced modern work environment present challenges in effectively utilizing these tools. While artificial intelligence (AI) has made significant strides, the realm of automated visualisation recommendation remains relatively underexplored. This gap highlights the necessity for systems that can autonomously generate visualisations, reducing the dependency on technical expertise and accelerating the data analysis process. By analysing dataset characteristics and providing a visualisation, the proposed system aims to democratize data exploration, allowing a broader audience to engage with data analysis.

3. Proof of concept

Initial implementations of the system with data from the NEXUS project at Porto de Sines demonstrated its effectiveness, receiving positive evaluations from users. The system provided valuable insights into logistics operations, facilitating data-driven decision-making and enhancing business intelligence efforts. The modular design of the system supports scalability, enabling it to handle increasing volumes of data without compromising performance. This scalability is crucial for large-scale businesses that deal with extensive datasets, ensuring the system remains effective as data demands grow. In Figure 2. It is possible to observe examples of the prototype built with the ideas of this work.

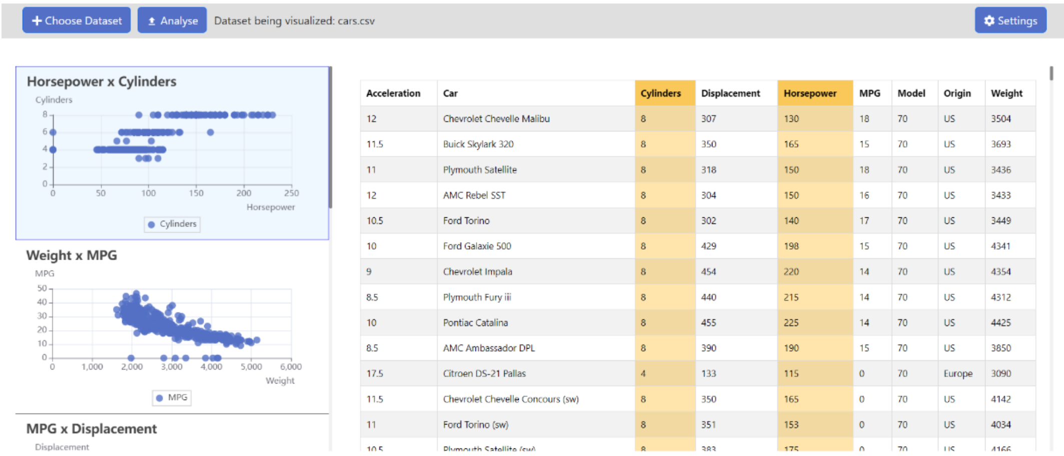

Figure 2. Working prototype of the proof of concept for the automated visualisation recommendation system. The visualization recommended highlighted on the left was generated using the two highlighted columns in orange. It is possible to have more than one visualization being recommended for the same dataset.

4. Conclusions

The proposed system aims to provide and improve data analytics by providing automated visualisation recommendations, empowering users with varying expertise levels to engage with complex datasets. By automating visualisation recommendations, our system democratizes data exploration, making it accessible to a broader audience, including those with limited technical knowledge. This accessibility enables users from diverse backgrounds to derive insights from complex datasets without requiring extensive technical expertise. The automated system significantly reduces the time and effort required for manual visualisation creation, allowing data scientists to focus on other critical tasks and accelerating the decision-making process. By streamlining the visualisation process, businesses can quickly access actionable insights, improving overall efficiency and productivity. The system's ability to democratize data exploration and reduce reliance on technical expertise makes it a valuable tool for businesses seeking to harness the power of data in the digital age.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, E.P and J.C.; methodology, E.P, J.C and D.M.; software, D.M. and J.M.; validation, E.P and J.C; formal analysis, E.P and J.C; investigation, D.M; resources, J.M.; data curation, D.M. and E.P. ; writing—original draft preparation, D.M and J.C .; writing—review and editing, E.P, J.C and J.M.; visualization, D.M.; supervision, J.C. and E.P.; funding acquisition, J.C.

and E.P. All authors have read and agreed to the published version of the manuscript.”. Authorship must be limited to those who have contributed substantially to the work reported.

Funding: Content produced within the scope of the Agenda" NEXUS - Pacto de Inovação - Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with n.º C645112083-00000059 (investment project n.º 53), and co-funded by national funds through the FCT – Foundation for Science and Technology, I.P., under the project/support 2022.15675.CMU

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CCUS and CO_2 transport by ship in Portuguese decarbonization scenarios: from pilot to large-scale

Paulo Mesquita [1,2*], Júlio Carneiro [2,3*], Pedro Madureira [2,3*], Pedro Pereira [1,2], Andrés Carro [6], Paula Afonso [1,4], Karwan Khudhur [1,2], Patrícia Fortes [5], Ricardo Chacartegui [7]

[1] Department of Geosciences, IIFA, University of Évora, 7000-671 Évora, Portugal; pmesquita@uevora.pt (P.M.); pmpereira@uevora.pt (P.P.); pafonso@uevora.pt (P.A.); karwan.khudhur@uevora.pt (K.K.)
[2] Institute of Earth Sciences (ICT), Center for Sci-Tech Research in Earth System and Energy (CREATE) 7000-671 Évora, Portugal
[3] Department of Geosciences, Sciences and Technology School, University of Évora, 7000-671 Évora, Portugal; jcarneiro@uevora.pt (J.C.); pedro@uevora.pt (P.M.);
[4] HERCULES Laboratory and IN2PAST, Associate Laboratory for Research and Innovation in Heritage, Arts, Sustainability and Territory, Institute for Advanced Studies and Research, University of Évora, 7000-809 Évora, Portugal.
[5] NOVA School of Science and Technology, CENSE and CHANGE NOVA University of Lisbon, Caparica, Portugal; p.fs@fct.unl.pt
[6] Universidad de Sevilla, Sevilla, Spain; andrescarro@us.es (A.C.)
[7] Universidad de Sevilla, Laboratory of Engineering for Energy and Environmental Sustainability, Sevilla, Spain; ricardoch@us.es (R.C.)

Abstract: The Portuguese target for carbon neutrality by 2050 will require the deployment of CO_2 capture, utilization and storage (CCUS). Although Techno-Economic Assessments (TEA) of CCUS scenarios targeting specific industrial sectors have been performed in Portugal in the scope of previous EU projects, the detailed analysis for the early stages of a CCUS chain, focusing on pilot scale, is necessary for policy makers and industry alike. Furthermore, ship transport may be a solution for a long-term large-scale CCUS scenario addressing the Sines industrial cluster, and in this scenario ship transport directly from the Sines port would play an important role. Within the CTS project (CO2 Transport and Storage directly from a ship) the technical and economic assumptions for designing a CCUS pilot in Portugal will be performed along with the study requirements of the possibility of direct CO_2 injection from a ship both for the pilot period and for a scenario focused on Sines emitters and infrastructure.

Keywords: Geologic CO_2 storage; CO_2 ship transport and injection; CCUS.

1. Introduction

Portugal's national decarbonization strategy is framed by multiple guidelines, including the revised National Energy and Climate Plan (PNEC 2030) [1], the Carbon Neutrality Roadmap 2050 (RNC 2050) [2], the National Hydrogen Strategy (EN-H2) [3], and the Portuguese Climate Law (DL98/2021) [4]. The updated PNEC 2030, adopted in 2024, sets more ambitious goals, such as a 55% reduction in greenhouse gas (GHG) emissions by 2030 (compared to 2005 levels), achieving carbon neutrality by 2045, and sourcing 51% of energy from renewables. This includes significant expansion of solar and wind energy, a 35% reduction in primary energy consumption, and leveraging green hydrogen to decarbonize industries and store energy. While the RNC 2050 initially placed less emphasis on Carbon Capture, Utilization, and Storage (CCUS), the 2024 PNEC revision highlights CCUS as essential for hard-to-abate sectors like cement production. The plan also explores integrating CCUS with low-carbon hydrogen production and sustainable fuels, alongside bioenergy with carbon capture and storage

(BECCS) for sectors like pulp & paper, and waste, aiming for negative emissions. Together, these strategies underline Portugal's commitment to a low-carbon, sustainable economy.

CCUS [5] represents a set of technologies that aim at reducing the CO_2 emissions from stationary facilities into the atmosphere (**Figure 1**). The emitted CO_2 would be captured in an energy or industrial facility where the flue gas is treated and the CO_2 isolated; after the purification the CO_2 stream usually needs to be transported to a location where it will be used to produce other materials, like synthetic fuels, or to an injection site where the CO_2 will be permanently stored in deep underground geological reservoirs.

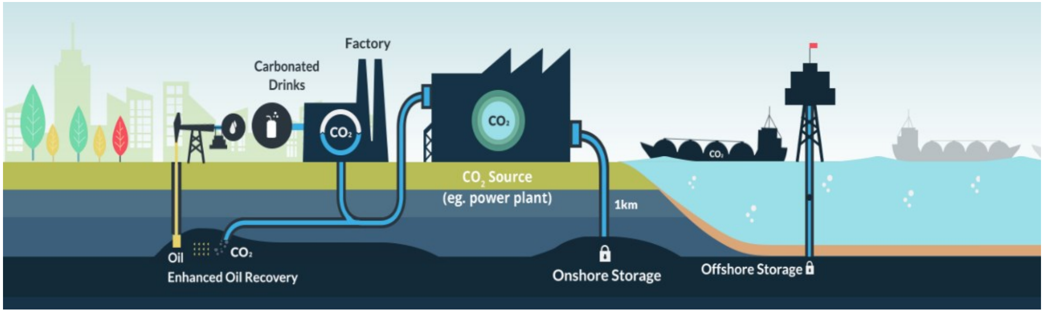

Figure 1. Scheme of the CCUS chain.

The transport of CO_2 in significant quantities can be done by pipeline, train and ship with multimodal solutions being possible in the same transport network. CO_2 pipelines exist in operation since the 70s in the United States, where CO_2 is used for EOR (enhanced oil recovery). Currently the country has more than 7200 km of pipelines dedicated to CO_2 transport that carry around 68 Mt/yr of CO_2. For efficiency, the transport of CO_2 via pipeline is performed at supercritical (temperature above 30 ºC) or dense (typical temperature range from -10 to 30 ºc) phases that demand pressures above 72 bar. In train and ship transport, the CO_2 is cryogenic usually in the configuration of low pressure (~6 bar, -50 ºC) or medium pressure (~15bar, -25 ºC). Train and pipeline transport of CO_2 are more mature technologies in relation to ship transport where only two dedicated ships for large quantities of CO_2 exist, with 7500 m^3 of capacity, and built under the scope of the Northern Lights project [6]. Nevertheless, the shipping industry of CO_2 transport is expected to expand in the next years. Currently, the option of injecting CO_2 directly from the ship into offshore reservoirs is also a topic of research, since it has the potential to avoid the necessity of offloading facilities rigs.

In Portugal, CCUS related studies have been developed since 2009 under the scope of multiple European level projects. The most recent projects (**Figure 2**) focused on the development and analysis of detailed long term CCUS scenarios until 2050 (StrategyCCUS) [7]; on the identification of suitable geological reservoir and it's dimensioning for CO_2 injection (PilotSTRATEGY) [8]; and in the assessment of the viability of transport and injection directly from ship in the offshore reservoir for national scenarios (CTS) [9].

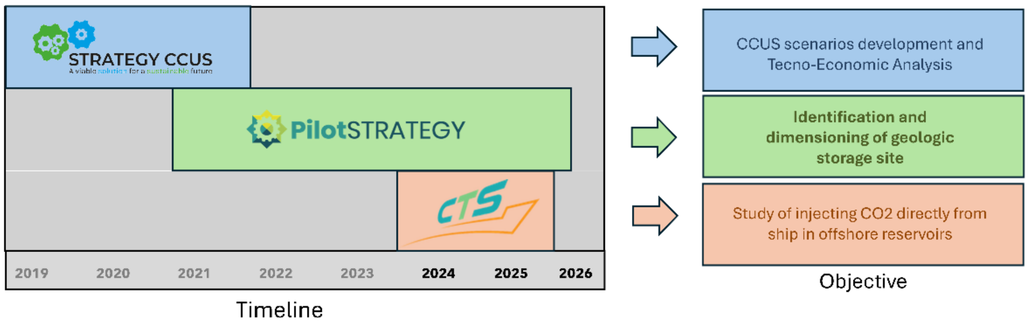

Figure 2. Recent CCUS projects with focus on Portuguese decarbonization scenarios.

This work aims at presenting the potential for CO_2 ship transport in Portuguese decarbonization scenarios both in an experimental pilot period that aims at testing the viability of capture in interested industries and testing the reservoir capabilities; and in a large-scale long-term scenario that considers the possibility of transporting the CO_2 captured from the Sines industrial cluster by ship to the offshore reservoir located near Figueira da Foz.

2. Pilot scenario

A pilot scenario was developed taking into consideration emitters interested in installing small-scale capture plants in Souselas and Marinha Grande. Flexible transport options, including direct injection from ships were considered for offshore storage to avoid the deployments of offshore pipelines or platforms. The design aimed at providing the needed CO_2 to conduct an injection pilot to validate the reservoir and injection models that have been developed in the Lusitanian basin in the scope of the project PilotSTRATEGY. The complete chain of processes, from capture to injection, was considered with focus on minimizing the deployment of permanent or hard-to-shift infrastructures.

Figure 3 depicts the pilot scenario scheme. The initial phase of the transport was considered to be by train, between both capture facilities and the Figueira da Foz port and by ship between the port and the offshore injection site. The CO_2 volume and transport conditions were matched between train and ship to allow for the CO_2 to be moved to the ship without the need for intermediate storage and/or intensive reconditioning. The considered train capacity was 4000 t with a roundtrip of ~12h including loading and unloading. The considered ship capacity was 4000 t with a roundtrip of ~80h and an injection rate of 15 kg/s of CO_2. Both train and ship roundtrips are matched for around 68 trips in the period of 3 years, with a transport capacity of 90,000 kt/y totalling 270,000 kt of CO_2.

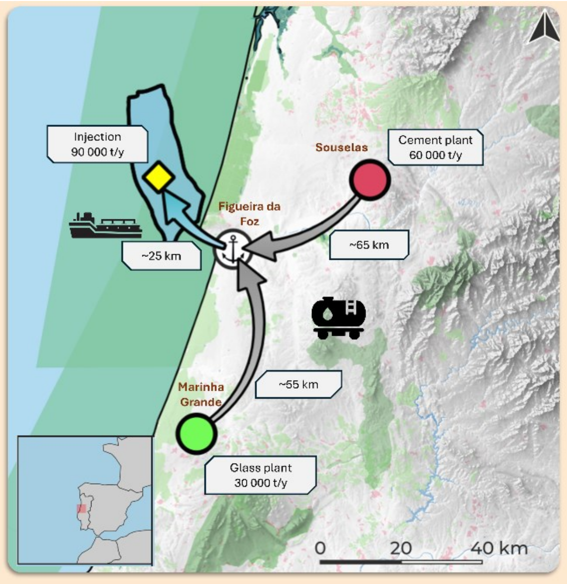

Figure 3. Schematics of the pilot scenario.

4. Towards large scale ship transport and injection

The CTS consortium is planning an innovative concept for the CO_2 transport by a ship. The project envisions bringing more flexibility to the CCUS chain, which would be supported by the construction of ships capable of transporting and directly injecting the CO_2 in the offshore reservoir without the need for permanent offshore platforms.

For the large-scale long-term scenario focused on Sines, some of the CO_2 emitters in the area would be considered for capture with an amount that could surpass 2 Mt of CO_2 per year, and the Sines port as an exportation hub for CO_2 since ships may benefit from the deep-water characteristics of Sines port. For this purpose, the port needs to be equipped with intermediate storage and equipment to prepare the CO_2 into the right conditions for ship transport.

Figure 4 portrays the long-term 2050 offshore scenario developed in the StrategyCCUS project where the transport would be exclusively by pipeline. A new approach on the CTS project will evaluate the inclusion of new emitters from the Sines industrial cluster and will evaluate the CO2 ship transport and direct injection.

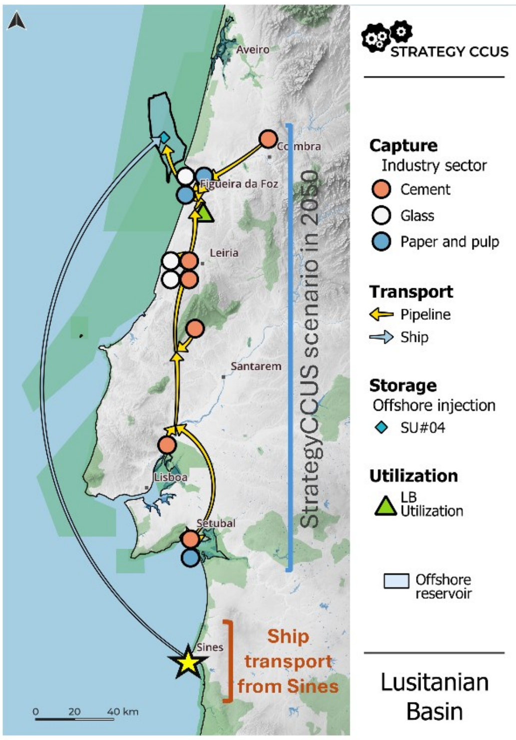

Figure 4. Strategy CCUS long term scenario with addition of the Sines cluster for ship transport.

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<table>
<tr><td>8h30</td><td>Reception of participants</td></tr>
<tr><td>9h00</td><td>Official Opening
Professor Hermínia Vilar - Rector of the University of Évora
Dra. Carmen Carvalheira – Vice-President of the Alentejo Regional Coordination and Development Commission
Eng. José Cacho - Board President of APS
Professor Teresa Batista – Agenda NEXUS coordinator at University of Évora</td></tr>
<tr><td>9h15</td><td>DIGITAL TRANSITION AND DECARBONIZATION IN MARITIME PORTS
Chair: Vitor Caldeirinha | Polytechnic Institute of Setúbal
Keynote speaker: HANS ROOK | International Port Community Systems Association (IPCSA)</td></tr>
<tr><td>10h00</td><td>ID58 | A systematic review of visualization tools for open data
Barbara do Nascimento Ramos[1]; Jéssica A Parente[1]; Evgheni Polisciuc[1]; João Correia[1] | [1]University of Coimbra</td></tr>
<tr><td>10h15</td><td>ID07 | Bibliometric Analysis and Evaluation of Geographical Visualization Platforms in Seaports
Crismeire Isbaex[1]; Francisco Costa[2]; Maria Teresa Folgôa Batista[1] | [1]University of Évora; [2]GEPOINT</td></tr>
<tr><td>10h30</td><td>ID19 | Observation At The Edge: A Novel Approach to Edge Node Security
Sofia Vaz[1]; Catarina Silva[1]; João Paulo Barraca[1]; Diogo Gomes[1]; Paulo Salvador[1] | [1]University of Aveiro</td></tr>
<tr><td>10h45</td><td>ID50 | A Container Transport Network Digital Twin to promote Sustainable Transport Practices: Concept Proof
Pedro Costa[1]; António M. Amaral[2]; Raquel Pereira[1]; Carlos Manuel Batista[1]; Marina Gonçalves[3]; João Lemos Nabais[1] | [1]IPS; [2]ISEP P.Porto; [3]MARLO</td></tr>
<tr><td>11h00</td><td>ID49 | Exploring the use of Digital Twins to optimize berth processes in Commercial Ports
Henrique Calhau[1]; Alberto Cardoso[1]; Jacinto Estima[1] | [1]University of Coimbra</td></tr>
<tr><td>11h15</td><td>ID30 | Open Data and Collaborative Maritime Platforms – a comparative analysis (online)
João M Marreiros[1]; Bruno Rocha[1]; João Graça[2]; Cláudio Pinto[3]; Vala Rohani[1]; Nelson Carriço[1]; Tiago Pinho[1]; Ana Mendes[4] | [1]Polytechnic Institute of Setubal; [2]MARLO; [3]APS; [4]ESCE/IPS</td></tr>
<tr><td>11h30</td><td>Coffee-break (Auditorium)</td></tr>
<tr><td>12h00</td><td>ENERGY TRANSITION
Chair: José Silva | Renewable Energies Chair of University of Évora

ID12 | Forecasting electricity demand in ports: current trends and future directions
Adrian Carrillo-Galvez[1]; Felipe Carmo[1]; Tiago Soares[1]; Zenaida Mourão[1]; Ilia Ponomarev[1]; João Pedro Araújo[2]; Eduardo Bandeira[2] | [1]INESC TEC; [2]APS</td></tr>
<tr><td>12h15</td><td>ID16 | ERE – Planning: a simulation tool for renewable energy projects in the logistic ports
Xumiao Lin[1]; Joana MR Correia[2]; Miguel Marques[1]; Ana Foles[2]; José A Silva[2]; Luis Fialho[2]; Pedro Horta[2] | [1]INEGI; [2]University of Évora</td></tr>
<tr><td>12h30</td><td>ID29 | Energy management system for ports considering battery energy storage systems
Igor Rezende[1]; Tiago Soares[1]; Adrian Carrillo-Galvez[1]; Felipe Carmo[1]; Zenaida Mourão[1]; João Pedro Araújo[2]; Eduardo Bandeira[2] | [1]INESC TEC; [2]APS</td></tr>
<tr><td>12h45</td><td>ID13 | Technical grid operating tool for application at the Port of Sines
Ilia Ponomarev[1]; Tiago Soares[1]; Adrian Carrillo-Galvez[1]; Micael Simões[1]; Felipe Carmo[1]; Zenaida Mourão[1]; João Pedro Araújo[2]; Eduardo Bandeira[2] | [1]INESC TEC; [2]APS</td></tr>
<tr><td>13h00</td><td>ID15 | Automated Wave Height Estimation and Overtopping Detection from Coastal Video Data
Tochukwu Ngene[1]; Fabio Santos[1]; Tiago Abreu[2]; Paulo Silva[1]; Telmo Cunha[1]; Paulo Baptista[1] | [1]University of Aveiro; [2]Polytechnic of Porto</td></tr>
<tr><td>13h15</td><td>ID59 | Long-term water monitoring: A valuable tool for the sustainable governance of port areas
Ana MAT Mata[1]; Ricardo MN Salgado[1]; Paula Chainho[1]; Luís Coelho[1]; Romeu Ribeiro[1]; Nuno Borges[1]; Dina Galhanas[1] | [1]Polytechnic Institute of Setubal</td></tr>
<tr><td>13h30</td><td>Buffet Lunch (Room 129)</td></tr>
<tr><td>15h00</td><td>SUSTAINABILITY IN PORTS
Chair: João Correia | University of Coimbra
Keynote speaker: STEPHANIE VAN DEN BERG | Portfolio manager Strategy & Innovation and Lead Sustainability at Portbase</td></tr>
<tr><td>15h45</td><td>ID03 | Logistics and Sustainability in the Mediterranean: A Critical Review of Challenges and Strategies for Italian Ports (online)
Amit Kumar Singh[1]; Yasir Hassan Khachoo[2]; Oscar Rosario Belfiore[3]; Giovanni Pugliano[3]; Guido D'Urso[3] | [1]Sapienza University of Rome; [2]University of Naples Parthenope; [3]University of Naples Federico II</td></tr>
<tr><td>16h00</td><td>ID04 | Characterization of the energy consumption and GHG production on the Sines Port
Teresa Batista[1]; Carmen Vásquez[1], Rodrigo Ramírez-Pisco[2], Luís Manuel Navas[3], João Figueira de Sousa[4], Patrícia Silva[5], Fátima Baptista[6], Lucas Marinho[1], Adriana Correa[3], João Araújo[7], Eduardo Bandeira[7] | [1]University of Evora; [2]RITMUS – University of Carlemany; [3]RITMUS – University of Valladolid; [4]NOVA University of Lisbon; [5]Figueira de Sousa, Transportes e Mobilidade; [6]MED –CHANGE - University de Évora; [7]APS</td></tr>
<tr><td>16h15</td><td>ID48 | Applications of Sentinel-5P Satellite Data for Monitoring Maritime Pollution
Saad Ahmed Jamal[1]; Crismeire Isbaex[1]; Maria Teresa Folgôa Batista[1] | [1]University of Evora</td></tr>
<tr><td>16h30</td><td>ID39 | The impact of shipping emissions over air quality in Portugal
Alexandra Monteiro[1]; Michael Russo[2] | [1]University of Aveiro</td></tr>
<tr><td>16h45</td><td>ID55 | Carbon sinking through coastal landscapes: Identifying opportunities for the Port of Sines
Lucas de Aquino Marinho[1]; Maria Teresa Folgôa Batista[1]; Maria da Conceição Freire[1] | [1]University of Evora</td></tr>
<tr><td>17h00</td><td>ID20 | Port Decarbonization and Green Jobs: A Pathway to Sustainable Economic and Social Growth
Gonçalo Lestre[1]; Margarita Robaina[1]; João C O Matias[1]; Miguel Oliveira[1] | [1]University of Aveiro</td></tr>
<tr><td>17h15</td><td>Break and Poster Session — 17h30 TRAPECIO (CYTED Network) Online Meeting - Room 131 (CES)</td></tr>
<tr><td>19h00</td><td>End of The day</td></tr>
<tr><td>19h30</td><td>Conference Dinner (Room 129)</td></tr>
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AGENDA – 11th December

Location | University of Évora

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9h00	**SMART PORTS, LOGISTICS and TRAINING (Part I)** Chair: *TIAGO PINHO* | Polytechnic Institute of Setúbal keynote Speaker: *ADIL AIT OUALIL* | Director of Maritime Operations - Tanger Med
9h45	**ID53 | Accurate Estimates of Transshipment Container Dwell Times at Maritime Ports** *Eugénio Rocha[1]; André Lima[1]; Pedro Macedo[1]; Mara Madaleno[1]* | [1]University of Aveiro
10h00	**ID35 | Digital transformation of maritime ports: The Smart Pre-Gate in the Port of Sines** *Juliana Basulo-Ribeiro[1]; Mariana Ribeiro[1]; João P. S. Silva[2]; André Correia[3]; Bernardo Macedo[4]; Rui Borges Lopes[1]; Carina Pimentel[5]; Leonor Teixeira[1]* | [1]University of Aveiro; [2]Polytechnic Institute of Setúbal; [3]APS; [4]EGAPI; [5]University of Minho
10h15	**ID42 | Sizing Study of Pre-Gate Control Checkpoints for Sines Container Terminal** *João P S Silva[1]; Bruno Rocha[1]; Ana Martins[2]; André Correia[2]; Ana Mendes[3]; Marcela Castro[1]; Tiago Pinho[1]* | [1]Polytechnic Institute of Setúbal; [2]APS; [3]ESCE/IPS
10h30	**ID34 | A simulation tool to forecast the behaviour of a new smart pre-gate at the Sines container terminal** *Raquel Gil Pereira[1]; Rui Borges Lopes[1]; Ana Martins[2]; Bernardo Macedo[3]; Leonor Teixeira[1]* | [1]University of Aveiro; [2]APS; [3]EGAPI
10h45	**ID26 | Exploring Cloud-Based Access Control for Seaports: Features, Barriers, and Benefits** *Maria R. Sabino[1]; Liandra Henriques[1]; João P. S. Silva[1]; João Marreiros[1]; André Mestre[1]; Bernardo Macedo[2]; Maria Cabrita[3]; Marcela Castro[1]; Tiago Pinho[1]* | [1]Polytechnic Institute of Setúbal; [2]EGAPI; [3]UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University of Lisbon.
11h00	**Coffee-break**
11h30	**SMART PORTS, LOGISTICS and TRAINING (Part II)** Chair: *Maurice Jansen* | Erasmus Centre for Urban Port and Transport Economics - Erasmus University (Rotterdam) Keynote speaker: *EDUARD RODES* | Port of Barcelona
12h15	**ID32 | Essential Competencies in Maritime and Port Logistics: A Study on the Current Needs of the Sector** *Luís Silva Lopes[1]; João Lemos Nabais[1]; Claúdio Pinto[2]; Vitor Caldeirinha[1]; Tiago Pinho[1]* | [1]Polytechnic Institute of Setúbal ; [2]APS
12h30	**ID37 | Open Innovation and Innovation Ecosystem in Maritime Port: Review and Research Agenda** *Maria R Sabino[1]; Claudio Pinto[2]; Maria Cabrita[3]; Marcela Castro[1]; Ana Mendes[1]; Tiago Pinho[1]* | [1]Polytechnic Institute of Setúbal; [2]APS; 3UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University of Lisbon.
12h45	**ID36 | Towards the integration of blockchain technology into eCMR management systems** *Francisco M. B. Carreira[1]; Paulo Rupino Cunha[1]; João NL Barata[1]; Jacinto Estima[1]* | [1]University of Coimbra
13h00	**ID40 | Three-Part Genetic Algorithm to Optimize the Outbound Train Loading Process in Railway Systems** *Gonçalo Correia[1]; Jacinto Estima[1]; Alberto Cardoso[1]* | [1]University of Coimbra
13h15	**ID18 | Evaluating Logistics Data for Machine Learning Applicability: A Decision Support Tool for Non-Experts** *Vasco Vieira Costa[1]; Diogo Costa[1]; Ângela Filipa Brochado[1]; Eugénio Rocha[1]* | [1]University of Aveiro
13h30	**Buffet Lunch (Room 129)**
14h30	**CYTED NETWORKS CONFERENCE** *Luis Telo da Gama* | CYTED Geral Secretary
14h45	TRAPECIO | **Tecnologías habilitadoras para edificaciones casi cero en Iberoamérica** *Rodrigo Ramirez Pisco* | University of Carlemany
15h00	RIMSGES | **Red de investigación en modelos de sistemas de gestión de energía sostenibles** *Silvia Román Suero* | UNEX
15h15	RITMUS | **Red iberoamericana de movilidad y transporte urbano sostenible** *Luis Manuel Navas Gracia* | University of Valladolid
15h30	IBEROMASA | **Optimización de los procesos de extracción de biomasa sólida para uso energético** *Borja Velázquez Martin* | Polytechnic University of Valenci
15h45	RIBIERSE | **Red para la integración a gran escala de energías renovables en los sistemas eléctricos** *Jesús De la Casa Hernandez.* | Polytechnic Higher School of Jaén
16h00	RIBEPA | **Red iberoamericana de pobreza energética y bienestar ambiental** *Alexis Perez Fargallo* | University of San Sebastián
16h15	EFIMOVI | **Eficiencia energética de los sistemas de movilidad urbana en Iberoamérica.** Red Latinoamericana de Investigación en Energía y vehículos Relieve *Jose Ignacio Huertas Cardozo* | ITESM
16h30	RIETI | **Red Iberoamérica de eficiencia térmica industrial** *Emérita Delgado Plaza* | Polytechnic Higher School of Litoral
16h45	REMAR | **Oportunidades de integración en redes eléctricas iberoamericanas de las energías del mar** *Marcos Lafoz Pastor* | Center for Energy, Environmental and Technological Research (CIEMAT)
17h00	**Closing Session** Professor Paulo Quaresma – Vice rector University of Évora Professor Orlando Fernandes – IIFA Deputy Director Professor Susana Filipe – CHANGE Executive Director DGTMP24 Organization Committee
17h15	**Coffee to go**
18h00	**BUS to Sines**
20h30	**Arrival to Sines (Free time)**

AGENDA – 11th December

Location | Hibrid Event (official language: Spanish)

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1ERA JORNADAS INTERNACIONALES TRAPECIO-RIMSGES /CYTED

UNIVERSITY OF ÉVORA – COLÉGIO DO ESPÍRITO SANTO (CES) - ROOM 131

9h00	**Inauguración**. A cargo de las autoridades universitarias. Autoridades NEXUS. Coordinadores de las redes CYTED
	MESA REDONDA 1
9h15	**Hacia la mejora de la gestión de energía mediante gemelos digitales: experiencias desde la red** Silvia Román – Coordinadora de la Red RIMSGES | *Universidad de Extremadura*
9h35	**Modelo de sostenibilidad para viviendas cero emisiones en Iberoamérica en el marco de la transición energética** Rodrigo Ramírez Pisco - Coordinador de la Red TRAPECIO | *Universitat Carlemany*
9h55	**Eficiencia energética y sostenibilidad en edificios zero energía ZEB** Javier Rey | *Universidad de Valladolid*
10:15	**Condiciones de sostenibilidad de las plantaciones agrovoltaicas** Borja Velazquez | *Universidad Politécnica de Valencia*
10h35	Preguntas y Debate
11h00	**Coffee-Break**
	MESA REDONDA 2
11h30	**Atividades Latecae/Brasil na rede TRAPECIO** Joyce Correa | *Universidad Federal de Viçosa*
11h50	**HTC Sostenible: Innovando con Recuperación Energética Eficiente** Beatriz Ledesma | *Universidad de Extremadura*
12h10	**Evaluación de materias primas alternativas, para la producción de biocombustibles mediante procesos bioquímicos, caso mucílago del cacao CCN51** Cristian Laverde | *Universidad de Quevedo*
12h30	Preguntas y Debate
	MESA REDONDA 3
12h50	**Transición hacia sistemas de refrigeración eficientes y sostenibles en edificios residenciales: un análisis de tecnologías, desafíos y oportunidades** Carmen Luisa Vasquez | *Universidad de Évora, Universidad Expo*
13h10	Preguntas y Debate
	CONCLUSIONES
13h00	Conclusiones de las Jornadas
13h20	**Cierre**

Poster Session – 10th and 11th December

Location | University of Évora

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ID05	**Identifying and Categorizing Ports Decarbonization Barriers through the Sociotechnical Systems Theory** *André Fadiga[1]; Joana O. Andrade[1]; João F. Bigotte[1]; Luís Miguel D. F. Ferreira[1] | [1]University of Coimbra*
ID06	**Advanced Unmanned Aerial Vehicles Applications in Maritime Ports: Decision Making, Enhancing Inspection, Navigation, and Emergency Response** *Gilvan Gomes de Lima[1]; Alexandre Santos[2]; Ana Mendes[1]; Marcela Castro[1]; Tiago Pinho[1] | [1]Polytechnic Institute of Setubal; [2]GeoSense*
ID08	**Resilience of information flow in port operations: a bibliometric analysis** *Carlos Manuel Batista[1]; Cláudio Pinto[2]; Tiago Pinho[1]; Ana Barroso[3] | [1]Polytechnic Institute of Setubal; [2]APS; [3]NOVA School of Science and Technology*
ID09	**Logistics and Technology Projections for 2030: A Comprehensive Marine Port Report** *Gilvan Gomes de Lima[1]; Bruno Rocha[1]; Nuno Gonilho[1]; Cláudio Pinto[2]; Ana Mendes[1]; Marcela Castro[1]; Tiago Pinho[1] | [1]Polytechnic Institute of Setubal; [2]APS*
ID10	**Advanced Detection of Container Codes and Defects in Port Scene Analytics** *David A Ornelas[1]; Jose António Santos[1]; Daniel D Canedo[1]; Antonio JR Neves[1] | [1]University of Aveiro*
ID11	**Integrating lifelong learning in R&I projects: The case study of the NEXUS Academy** *Fabianne A Ribeiro[1]; Antonio JR Neves[1] | [1] University of Aveiro*
ID14	**A decision support system for planning and scheduling port operations: conceptual architecture** *Catarina C Carvalho[1;]; Mahdi Homayouni[2]; Jorge Pinho de Sousa[1]; Catarina Marques[1]; Ana Maria M. Rodrigues[1] | [1]INESC TEC; [2]Constructor University Bremen gGmbH*
ID17	**Towards Equipment Operations Optimization through a Novel Efficiency Analysis Model** *Syed Muhammad Taqi Raza Kazmi[1]; Eugénio Rocha[1]; Ângela Filipa Brochado[1] | [1]University of Aveiro*
ID21	**Energetic transition solutions for ports and logistics operations** *Gonçalo Lestre[1]; Margarita Robaina[1]; João C O Matias[1]; Miguel Oliveira [1] | [1] University of Aveiro*
ID22	**Artificial Intelligence Advancements in Maritime Sustainability** *Vala Ali Rohani[1]; Ines Ferreira[1]; Ana Mendes[1]; Tiago Pinho[1]; Nelson Carriço[1] | [1]Polytechnic Institute of Setubal*
ID23	**NEXUS: A 5G Strategic Vision for Sines' Port of the Future** *António João M Bastos[1]; Francisco M Fontes[1]; André Coelho[2]; Manuel Ricardo[3] | [1]Altice Labs, S.A.; [2] INESC TEC; [3]INESC TEC and University of Porto*
ID25	**The legal framework of digitalization and decarbonization of ports** *Marcelly F Gullo[1]; Stefani Patz[1]; Carla Barbosa[2] | [1]IJ/FDUC; [2]University of Coimbra*
ID28	**Benchmarking Performance Indicators: A Conceptual Report Toward a Multi-Scalar Approach to Port Performance** *Barbara P. Fontainha[1]; Antonio Santos[2]; Ana Mendes[1]; Marcela Castro[1]; Tiago Pinho[1] | [1]Polytechnic Institute of Setubal; [2]APS*
ID31	**Interactive Dashboards for KPIs Monitoring in Seaports: A Proof of Concept at the Port of Sines** *Liandra L.S Henriques[1]; Diana Marques[1]; Antônio Rosa[1]; Samuel A. B. Martins[2]; Miguel Lopez[1]; António M. Amaral [3]; Ana Mendes[1] | [1]Polytechnic Institute of Setubal; [2]APS; [3]ISEP P. Porto;*
ID33	**Smart Ports and Terminal Logistics: Design and Development of a Business Intelligence System** *Marco Gonçalves[1] ;Cátia Salgado[2] ;Amaro F. de Sousa[3];Leonor Teixeira[1] | University of Aveiro[1]; APS[2]; Instituto de Telecomunicações - UA[3]*
ID38	**Benchmarking Performance Indicators: A Conceptual Report Toward a Multi-Scalar Approach to Port Performance** *Barbara P. Fontainha[1]; Antonio Santos[2]; Ana Mendes1; Marcela Castro[1]; Tiago Pinho[1] | [1]Polytechnic Institute of Setubal; [2]APS;*
ID41	**Container License Plate Detection and Recognition using Multi-Frame Analysis** João Geirinhas[1]; Jacinto Estima[1]; Catarina Silva[1] | [1]University of Coimbra
ID43	**Temporal Analysis of the shipping movements at the Port of Sines (2010 - 2023)** *Maria Teresa Folgôa Batista[1]; Luis M. C. Rosa [1]; Francisco António M.C.N. Borges[1]; Crismeire Isbaex[1] | [1]University of Evora*
ID44	**On-demand 5G Private Networks using a Mobile Cell** *André Coelho[1]; José Ruela[1]; Gonçalo Queirós[1]; Ricardo Trancoso[1]; Paulo Furtado Correia[1]; Filipe Ribeiro[1]; Helder Fontes[2]; Rui Campos[1]; Manuel Ricardo[1] | [1]INESC TEC and University of Porto; [2]INESC TEC*
ID45	**Predicting cloud-based Access Control System Usage** *Joana R Oliveira[1]; Victor M Barbosa[1]; Ana Mendes[1] | [1]Polytechnic Institute of Setubal*
ID46	**Data standards as tools to respond to the maritime sector's new challenges** *João M Marreiros[1;] Paula Miranda[1]; João Carreira[1]; Mónica Oliveira[2]; Nuno Alves[2]; Tiago Pinho[1]; Ana Mendes[1]; Nelson Carriço[1] |[1]Polytechnic Institute of Setubal; [2]ESRI*
ID47	**Simplifying Depot Management with the use of a Digital Twin** Rodolfo I Santos[1] | [1]DEVLOP
ID51	**Development of an Optimization Model for Rhip Resource Al-location of a Major Portuguese Port** Diogo M Felicissimo[1]; Nelson Carriço[1]; José Rui Figueira[2] | *[1]Polytechnic Institute of Setubal;* [2]Technical University of Lisbon
ID54	**Smart Impact Management of KPIs on Maritime Ports** *Ângela Filipa Brochado[1]; Lara Esteves[1]; Eugénio Rocha[1] | [1]University of Aveiro*
ID56	**Towards an Automated Visualization Recommendation System for Open Data Platforms** *Duarte Meneses[1]; Evgheni Polisciuc[1]; João Macedo[1]; João Correia[1] | [1]University of Coimbra*
ID57	**Management of wastewater from maritime ship in port areas** Nigme E Cadenas[1] | [1]UNEXPO
ID60	**CO_2 Transport and Storage directly from a ship: flexible and cost-effective solutions for European offshore storage** Pedro Madureira et al. [1] | *[1]University of Evora*

LIST OF AUTHORS

LIST OF PARTICIPANTS

Abdulraheed Adeboye Ajibade
Abiola Daniel Ogunsola
Acácio Vaz Pires
Adalberto Pereira de Araujo Junior
Adelaide João G. de A. Bernardino Máximo
Adrian Galvez
Adriana Correa Guimareas
Adriano Soares Vieira
Afonso Ribeiro Campos
Ait Oualil
Alexandra Correia
Alexis Pérez Fargallo
Ali Raza
Amit Kumar Singh
Ana de Jesus Mendes
Ana Filipa Rodrigues Farinha
Ana Maria Álvares Tavares da Mata
Ana Raquel Gil Pereira
Ana Rita Antunes Mira Martins
André Alexandre Lachkeev Mestre
André da Silva Lima
André Filipe Madureira Gouveia Ferreira
André Filipe Mateus Pacheco da Palma Correia
André Filipe Pinto Coelho
André Manuel dos Santos Fadiga
Andreia Alves
Ângela Filipa Brochado
Antonio Jose Dionisio Varela
António Manuel Pereira da Silva Amaral
Antonio Maria Pusceddu
Arnaldo Pereira Gonçalves Frade

Barbara de Paula Fontainha
Bento Manuel Domingues
Bernardine Chigozie Chidozie
Bianca Silva Rocha
Borja Velázquez Martí
Bruno Campos Pedroza

Carla Maria Amorim Marques
Carla Sofia Peixoto Pedroso
Carlos Alberto Goncalves Pires
Carlos Alberto Santos de Oliveira
Carlos Manuel de Oliveira Batista
Carmen Luisa Vásquez Stanescu
Carolina Silva
Catarina Carvalho
Catarina Marques
Catarina Sofia Almeida Henriques
Cátia Cristina Ferreira Barreto Encarnado
Cátia Saraiva Vicente
Cátia Sofia Silva Salgado
Célia Carina Gomes Barreira
Christine Kim
Cláudia Cavaco Henriques
Claudia Susana Sánchez Parra
Cláudio José Pinto
Crismeire Isbaex

Daniel Filipe Cabral Maré da Silva Dias
Daniel Lopes Silva Janeiro
David Alexandre Ornelas
David José da Mota Geleia
Diana Sofia Pinho Marques

Eduard Rodes
Eduardo Moutinho
Erharuyi Osarodion
Eugénio Rocha
Eulália Vanessa Antunes
Eunice da Conceição B C Matos Rodrigues Guerreiro
Evgheni Polisciuc

Fábio André Carvalho dos Santos
Fernando Jorge Lima dos Santos Barros
Fernando Manuel Garcia Ferreira Grilo
Flávio Miguel Ramos Carpinteiro
Francisco António Marques Calado Nunes Borges
Francisco Fernandes Costa
Francisco Fontes
Francisco Javier Rey- Martinez
Francisco Luís Brinó Câmara
Francisco Manuel Marques Fontes

Gabriel olusoji Moses
Gabriel Vieira Gomes
Gilvan Gomes de Lima
Gonçalo Azevedo
Gonçalo Moura Lestre

Hans Rook
Helder Martins Fontes
Helena Luisa Leitão de Oliveira
Henrique Antunes Cortez de Campos Calhau
Hugo André Santos da Cunha Bastos
Hugo Guedes Lopes
Hugo Miguel da Silva Carvalho

Ianira Mendes Nhina
Igor Roberto Rezende e Castro de Abreu

2024

BOOK OF ABSTRACTS

ISBN 978-972-778-413-4