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# Decision-support system for the management of truck stays at seaports

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**Abstract**

This work presents a decision-support system for predictive analysis of truck arrivals, dwell times and possible congestion situations in seaport, through a methodology that encompasses machine learning algorithms, data visualization tools and discrete-event simulation models. This decision-support system makes it possible to have a detailed planning of the arrival and transit times of trucks in the port to predict land congestion events; and to know in advance the needs in relation to services or stopovers, and how long each truck will be in the port facilities. The system also allows for the planning and sizing of waiting areas according to expected arrivals and dwell times of trucks in port, at the same time that it optimizes port value spaces, and reduces unnecessary journeys and associated emissions, by evaluating the relationship between the sea side and the demand in land accesses. This will eventually help to improve coexistence and port-city integration between urban and heavy traffic. The system has been validated in the Port of Santander (Spain) with satisfactory results in terms of operational improvement.



*Keywords:* Seaport; machine learning; data visualization; simulation model

## 1. Introduction

The port growth experienced in recent years has led to an increase in activity not only at sea, but also on land [1]. However, in general, port management has historically focused on the sea side, while on the land side there is no monitoring and management capacity commensurate with its growth. Specifically, when a vessel arrives at port and the loading and unloading operations are carried out, the goods can either be found or stored in port, or they can be received and delivered simultaneously. In any case, port activity is necessarily linked to land transport, which

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guarantees its distribution, whether the maritime transport is carried out in the traditional way (goods only) or whether the trucks themselves are transported on board (roll-on/roll-off).

Digital systems in seaports are becoming increasingly common to manage and optimize the movement of goods through the port [2]. One such system is the truck access registration system, which tracks the arrival and departure of trucks at the port. This system includes the use of gate cameras and sensors, as well as a computer database that records the arrival and departure times of trucks. The truck access registration system is critical to efficient port management. It enables managers to track the movement of goods and identify bottlenecks in the system. This data can be used to optimize the flow of goods through the port, reducing waiting times and increasing efficiency.

Decision-support systems (DSS) are essential in this environment because of the sheer volume of data that needs to be analyzed and acted upon. With thousands of trucks arriving and departing the port every day, it is impossible for managers to make informed decisions without the aid of a computerized system. Decision-support systems use machine learning algorithms to analyze data, identify patterns, and make recommendations [3]. These systems can also simulate different scenarios to help managers make more informed decisions about how to allocate resources and optimize the flow of goods through the port. For these reasons, we have developed a decision-support system aimed at managing truck stays at seaports that exploits the existing data by means of machine learning algorithms, visualization tools, and a simulation model. This decision-support system has been validated in the Port of Santander (Spain) with satisfactory results.

The remainder of this paper is organized as follows. Section 2 provides an overview of the existing literature on the use of decision-support systems and management of trucks at seaports. Section 3 describes the decision-support system developed. Section 4 analyzes the experiments carried out to check the suitability of the system developed. Lastly, section 5 summarizes the main conclusions and discusses some promising lines for further research.

## 2. Literature review

Decision-support systems have the potential to revolutionize the way trucks are managed in maritime ports. With the rapid advancement of technology, automated and intelligent solutions have become increasingly popular in the transportation industry. In the following paragraphs, we will conduct a brief literature review of decision-support systems designed to manage trucks in maritime ports.

Chen and Guestrin offer a thorough examination of the prevailing scholarship on container port drayage research, analyzing it from various methodological approaches, such as model creation and algorithmic design, as well as technological perspectives, including self-driving trucks and blockchain technology. Based on their paper, container port drayage entails the transportation of containers to and from terminals and clients [4].

In their article, Mar-Ortiz *et al.* explore the challenges, analytical approaches employed to scrutinize data, and technological breakthroughs that delineate the existing standard for decision-making systems in the port and maritime supply chains. They pinpoint the shortcomings in the blueprint and creation of decision-making systems that can augment the functioning of port and maritime supply chains. Furthermore, their study highlights that a decision-making system can assist human judgment by granting access to pertinent knowledge and backing the selection of clearly-defined alternatives [5].

Munim *et al.* explore the utilization of massive data from the Automatic Identification System (AIS), energy effectiveness, anticipatory analytics, and digital change in the shipping sector. Additionally, they furnish potential areas of investigation for forthcoming studies [6].

Ambrosino and Peirano conducted research on the administration of a group of trucks that offer container pickup and delivery services (known as drayage) to a maritime container terminal. The researchers put forward a plan for managing truck arrivals that takes into account the objectives of both the terminal and trucking companies. They put the model to the test using actual data from a container terminal in the United States, and the findings indicated that it could decrease the amount of time that trucks spend waiting by up to 50%, all the while keeping the terminal's utilization rates high [7].

Moreover, Lange *et al.* examine the obstacles that truck drayage encounters within container ports as a result of the continuous expansion of container vessel dimensions [8]. Additionally, Li *et al.* put forward a deep learning approach that combines Gated Recurrent Unit and Fully Connected Neural Network, which uses fusion technology to forecast daily truck arrivals [9].

Finally, Andritsos examines the issue of port security and outlines the challenges involved in improving port security without imposing excessive penalties on trade or port-related activities. His main focus is on managing identities and controlling access [10]. Giuliano and O'Brien address the reduction of truck emissions at marine port terminals. They suggest three possible methods: expanding the duration of truck pickups and deliveries, establishing a scheduling mechanism for trucks, or minimizing truck waiting times at terminal entrances. These methods were authorized by legislation to minimize truck queues at gates. The authors propose that terminals can avoid fines by extending full-service gate hours to 70 per week (65 hours at the Port of Oakland) by introducing evening or weekend gates to spread out truck traffic or by providing a gate appointment system for cargo container drop-off and pick-up [11]. Additionally, Chen *et al.* propose a two-phase optimization approach to improve the pattern of truck arrival at ports. The first phase determines a system-optimal truck arrival pattern, while the second phase identifies an appropriate pattern of time-varying tolls that leads to the optimal arrival pattern. A procedure to address the time-dependent queuing system at the port is created by them. This involves identifying a truck arrival pattern that minimizes both total waiting time and discomfort. Subsequently, they generate toll rates that vary over time to optimize the truck arrival pattern, while simultaneously minimizing the average toll rate [12].

The paper at hand presents a novel approach that distinguishes itself from previous studies in several key aspects. Firstly, it proposes a unique algorithm that surpasses existing methods in terms of efficiency and accuracy. By incorporating advanced machine learning techniques, superior performance in complex scenarios is obtained. Secondly, it emphasizes the integration of simulation models into the research framework. By seamlessly integrating these models, it is possible to capture intricate dynamics and simulate various scenarios, enabling a more comprehensive understanding of the system under investigation. Lastly, the decision-support system incorporates visualization tools that enhance the interpretation and communication of the findings. These tools provide intuitive and interactive visual representations of the analyzed data, allowing researchers and practitioners to gain valuable insights effortlessly.

## 3. Decision-support system

The proposed decision-support system is designed to improve indicators related to infrastructure use, productivity and efficiency of the port's land connectivity, through intensity of infrastructure use in the delivery/reception of goods through trucks, as well as the modal distribution of land transport systems and efficiency in connectivity with the land system. This line of action is designed to achieve the following specific objectives:

1. Identify in advance the values of the indicators related to the stay and transit of trucks in the port. Some of these indicators are the following:

    - *Truck-turn time*. This indicator measures the time the truck remains at the port, from the time it enters to the time it leaves. The shorter the time spent at the port, the more efficient the use of the infrastructure and the greater the capacity to serve the trucking industry, which improves the competitiveness of the terminals and the port.
    - *Intensity of infrastructure use in the delivery/receipt of goods*. This indicator compares the current movement of goods by road with the port's capacity for delivery/receipt by road transport. Efficient use of the port's road network reduces congestion at the exit, reducing waiting times and lowering costs in the logistics chain, as well as reducing port-city problems.
    - *Intervals between truck arrivals*. This indicates the time elapsed between consecutive arrivals of trucks at the port. A shorter time between vehicles constitutes a greater operational pressure and a greater demand on efficiency.
    - *Total distance traveled in port*. This indicator establishes the number of meters traveled by trucks within the port infrastructure and each of its zones. Reducing congestion reduces the amount of meters traveled and, consequently, the environmental impact of vehicles.

2. Provide the port manager with a detailed planning of the stay and transit of trucks in the port infrastructure. This planning will consist of an estimated arrival and departure time for each truck in each area of the port.

3. Order waiting areas within the port. Having accurate information about the reception/delivery of goods, as well as reliable estimates about the stay and transit of trucks allows to adapt a waiting area for each vehicle based on its characteristics and those of its cargo.

The decision-support system is designed to be used in a simple way by port managers. With this objective in mind, the creation of a software application that will present the information to the manager, and also other stakeholders as truck drivers, in an understandable and simple way is proposed. This software will allow the port manager to establish preferences and criteria to order the stay and transit of vehicles in the port infrastructure, while evaluating the existing alternatives when creating access schedules for trucks. Figure 1 presents an outline of the structure of the system proposed.

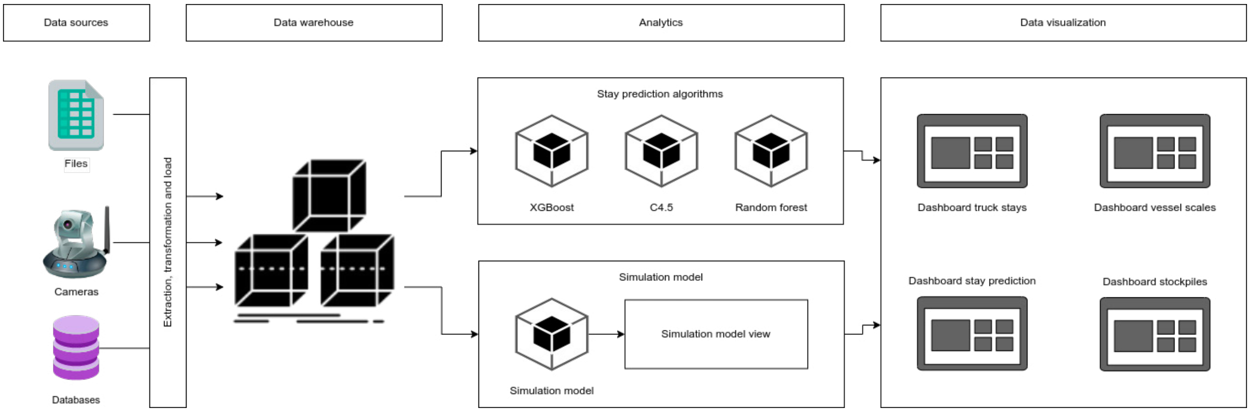



Fig. 1. Overview of the decision-support system

It is organized into the following interconnected technological components.

### 3.1. Extraction, transformation and loading

This component consolidates in the data warehouse (described in the following subsection) the different data coming from the Port Authority and/or terminal operator that have an impact on the stay and transit of trucks. For example, access control management software, cargo and port of call databases (DUEPort, INTEGRA2, PMS, PCS), specific management systems (TOS), data files, other databases, port access control cameras, etc.

### 3.2. Data warehouse

A system that aggregates and combines information from different sources coming from the Port Authority and/or terminal operator into a single and centralized data warehouse. This data warehouse supports the prediction of the stays and transit of vehicles by means of simulation models and machine learning techniques. In the case of the decision-support system, it will allow port managers to run analyses on large volumes of historical data in ways that a standard database simply cannot.

Besides, in future versions of the decision-support system, the scalability of the data warehouse, together with the automated data management, offers an opportunity to store information on road traffic, weather conditions, port capacity, individual vehicle characteristics and other data relevant for the prediction. This information can be continuously updated in real time, so that predictions are accurate and provided to stakeholders in an efficient manner.

### 3.3. Analytics

It is an artificial intelligence system aimed at extracting useful knowledge from the data collected in the data warehouse, by means of machine learning algorithms and simulation models.

#### 3.3.1. Stay prediction algorithms

Prediction algorithms based on machine learning techniques are a fundamental part of the decision-support system designed to predict the time it will take trucks to access a port. These algorithms use mathematical and statistical models to analyze historical and current data on vehicles accessing the port, and make predictions about how long it will take vehicles to arrive at the port in the future, as well as how long they will stay inside the port facilities.

In general, the prediction algorithms based on machine learning techniques used in this decision-support system follow a similar process, in which historical data is collected and analyzed to identify patterns and trends that can be used to make accurate predictions. These patterns and trends are used to train the model and, once the model is trained, it is used to make predictions about future data.

In the specific case of this decision-support system, the prediction algorithms use data from trucks accessing the port to make predictions about how long it will take to reach and be at the port in the future. This may involve analyzing factors such as time of day, type of cargo, vehicle size and other factors that may influence the arrival and dwell time of trucks. C4.5 [13], XGBoost [14], and Random forest [15] are integrated in this component of the system. All the algorithms have been programmed in Python and deployed as Docker containers.

The machine learning algorithms designed significantly enhance the performance of previous algorithms documented in the literature and the existing techniques available in the field for determining the stay of trucks when they are combined. By leveraging advanced data analysis and predictive modeling capabilities, the algorithms exhibit superior accuracy, efficiency, and robustness. Through extensive training on large-scale datasets, they are capable of effectively recognizing patterns, identifying relevant features, and making precise predictions regarding the duration of truck stays. Furthermore, the algorithms demonstrate adaptability to various scenarios and exhibit the potential to handle complex and dynamic real-world conditions, thereby outperforming traditional methods and providing substantial advancements in the domain of truck stay determination.

### 3.4. Simulation model

The discrete-event simulation model, implemented with a Java-based simulation library [16], defines vessels and trucks as entities, and model the arrivals of both to the port. The model also defines the routes the trucks follow to get to the waiting area, as well as the restrictions in terms of available space within the transshipment area. The (expected) arrival of a vessel triggers the creation of certain number of trucks that, according to the planned transshipment operations, arrive at the port, perform the operation, return to their warehouse and repeat the process if required. The outcomes of the simulation model include the detail of the routes, the usage of different port resources, and the total time devoted to complete all the tasks required by a vessel.

### 3.5. Visualization and reporting

Data visualization through dashboards is essential to help port managers quickly identify data trends. In particular, the graphical representation of data sets makes it possible to visualize congestion situations, identify reasons for delays, etc. At the same time, this information can be easily communicated to stakeholders through a notification system (*e.g.* apps, mail or internal messaging).

In order to satisfy the objectives proposed in this article, the following dashboards have been designed:

- The first dashboard is designed to manage truck stays at seaports. It provides real-time information on the availability of truck parking spots, the duration of stays, and the expected time of departure. It also allows the user to manage and track the movements of individual trucks.
- The second dashboard is focused on managing the scales of vessels. It provides information on the current status of vessel scales, including their availability, location, and capacity. This dashboard enables the user to schedule and coordinate the scaling of vessels in a timely and efficient manner.
- The third dashboard is aimed at predicting the stay of trucks at seaports. It utilizes data on historical truck stays such as entrance and departure gates or type of vehicle, among other relevant factors to generate accurate forecasts of truck arrival and departure times. These predictions help seaport managers to better plan and allocate resources for the handling of trucks.

- The fourth dashboard is designed to relate truck access with vessel scales and imports and stockpiles of goods. It provides information on the availability and status of goods, as well as the expected arrival and departure times of trucks and vessels. This dashboard enables seaport managers to optimize the flow of goods through the seaport, setting up waiting areas, and minimize delays and congestion.

## 4. Practical experience

### *4.1. Port of Santander (Spain)*

The Port of Santander[1] is a major commercial and passenger port located in the city of Santander, Spain. It is situated on the Bay of Santander, which is part of the Cantabrian Sea in the northern coast of Spain. The port has a long history dating back to the Roman Empire, and today it is one of the most important ports in the region. Figure 2 shows the infrastructure and location of the Port of Santander[2].

(a) Infrastructure (b) Location

Fig. 2. Port of Santander (Spain)

The port is equipped with modern facilities and offers a range of services to shipping companies and other maritime stakeholders. It has multiple piers and docks capable of handling a variety of vessels, including container ships, ro-ro (roll-on/roll-off) vessels, bulk carriers, and cruise ships. The port also has a large marina that can accommodate recreational boats and yachts.

The Port of Santander is a key gateway for trade between Spain and the rest of Europe, and it handles a significant volume of cargo traffic. It is well connected to major road and rail networks, which provide access to major industrial and commercial centers in the region. The port also has extensive warehousing facilities and offers a range of logistics and supply chain services. In addition to its commercial activities, the Port of Santander is also a popular destination for cruise ships and other passenger vessels. The port has a modern passenger terminal equipped with all necessary facilities, including check-in counters, baggage handling, and customs and immigration facilities. The city of Santander itself is a popular tourist destination, known for its beautiful beaches, historic landmarks, and vibrant culture.

### *4.2. Input data*

The decision-support system has been validated using data from the operations of the Port of Santander. In particular, data related to the access of trucks as well as ship calls during the years 2021 and 2022 have been used. This dataset is compose of more than 500,000 accesses of trucks and near 1000 vessel scales in the time windows under analysis.

[1] https://www.puertosantander.es
[2] Images obtained from Open Stree Maps (https://openstreetmap.org)

The provided data are composed of truck access records, registered through QR-based systems and cards with RFID technology. These datasets include detailed information on truck access. As a summary, some of the main variables are included date and time of entry, date and time of departure, access and exit used by the truck. It can be any of the 3 existing gates in the port or maritime access, in case of ro-ro traffic, truck registration number, personal information about the truck driver, and information about the company to which the truck belongs, among others.

Data from the port's information systems on vessel calls and associated goods are available. The following variables are of special interest for this work:

- *Information on the vessel provided through the Automatic Identification System (AIS)*. This includes for example, Maritime Mobile Service Identity, vessel type and cargo type, among others.
- *Types of goods*. This includes a detailed breakdown of the types of goods to be operated in the call as well as the consignees of the goods.
- *Operational requirements*. Services required by the vessel during the call. These include information related to the personnel employed, mechanical items considered, etc.
- *Berthing area*. The type of operation to be carried out on the vessel as well as the type of goods and volumes considered impose the use of certain docks and schedules.

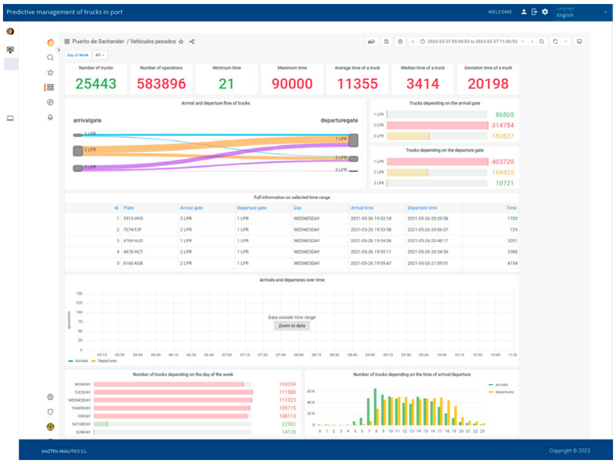
### *4.3. Dashboards*

Dashboards play a critical role in managing truck access to ports and achieving the objectives proposed. They provide real-time visibility into key metrics and performance indicators, enabling port operators and trucking companies to make data-driven decisions that optimize port operations and minimize waiting times. With regard to truck access, dashboards provides insights into the number of trucks waiting in queue, their average wait time, and the number of trucks being processed per hour. This information can be used to identify bottlenecks and inefficiencies in the trucking process, allowing port operators to make adjustments and improve throughput. Dashboards are also used to monitor truck arrival times and predict future demand, allowing port operators to allocate resources more effectively and avoid overloading the port with more trucks than it can handle. This can help to reduce queue times and ensure that the port is operating at maximum capacity. Furthermore, dashboards provide real-time information on the status of individual trucks, allowing operators to track the movement of goods and ensure that they are being processed efficiently. This helps to reduce the risk of delays and improve overall port productivity.

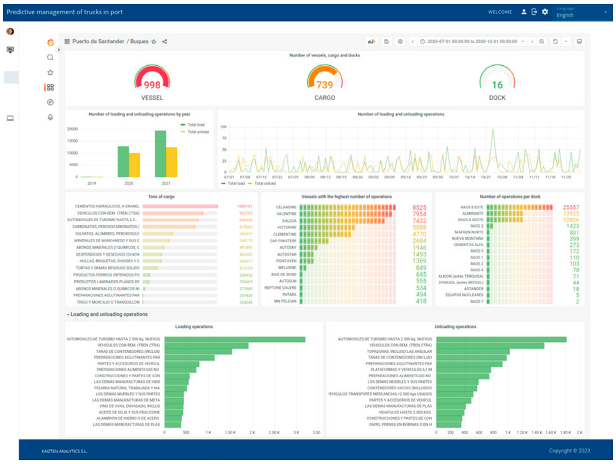
The decision-support system dashboard for managing truck stays at seaports provides a comprehensive overview of critical information related to truck movements and stays within the port premises. The dashboard presents real-time data about truck information, stay times, truck accesses over time, and gates used to access and exit the port. In addition, the dashboard displays graphical representations of the number of operations and truck movements, allowing the user to analyze trends and patterns in truck traffic. The system also provides insights into the availability of dock space and identifies potential bottlenecks in the trucking operations.

Figure 3 depicts the dashboards created for this decision-support system. All dashboards are designed to be intuitive and user-friendly, allowing operators to quickly access the information they need to make informed decisions. They provide a single view of all key performance indicators, and also include advanced features for predictive analytics, enabling operators to anticipate potential issues and take corrective action before they occur. Overall, the dashboards provide a powerful tool for helping to streamline operations, improve efficiency, and reduce costs. The existing dashboards are the following:

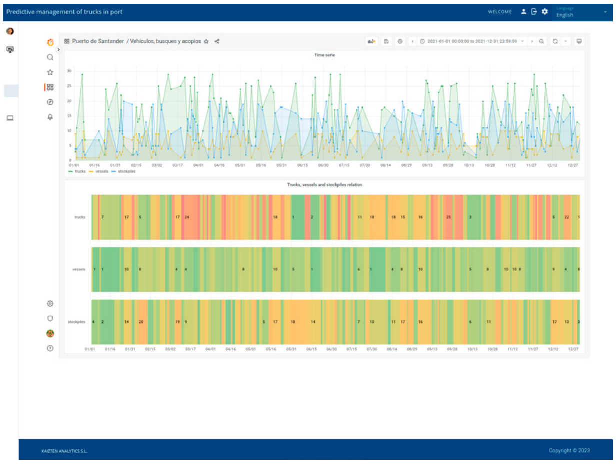
- Truck stays (figure 3(a)). This dashboard monitors the time that trucks spend within the port, providing valuable insights through relevant indicators. This includes the number of trucks arriving and departing during specific time frames, as well as statistics on the duration of their stay (including minimum, maximum, average, and variance). Additionally, the system tracks the entry and exit points utilized by each truck.
- Vessel scales (figure 3(b)). This dashboard showcases the loading and unloading operations of the vessels that scale in the port. It provides valuable indicators such as the number of operations performed by each vessel and the corresponding tonnage of cargo, grouped by vessel, dock, or type of operation (loading or unloading). This data provides a comprehensive overview of the vessel's operations and can be used to identify trends.



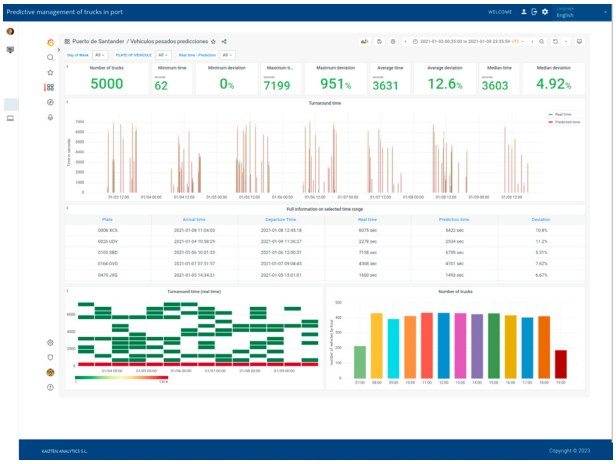
(a) Management of truck stays



(b) Management of vessel scales



(c) Relationship between truck stays, ship calls and goods stockpiles



(d) Prediction of truck stays

Fig. 3. Dashboards

- Trucks, vessels and stockpiles relationship (figure 3(c)). The relationship between trucks, vessels and stockpiles can be critical for efficient port operations. This dashboard refers to correspondence between trucks, vessels and cargo stockpiles over time. Specifically, it involves the coordination and timing of truck arrivals and departures with vessel arrivals and departures, as well as the management of cargo stored in stockpiles. Effective management of this relationship can lead to improved productivity and reduced delays in port operations.
- Trucks stays prediction (figure 3(d)). The decision-support system utilizes machine learning algorithms to make predictions about the duration of time that trucks will spend inside the port. These predictions are displayed on a dashboard, along with detailed information about the accuracy of the predictions. Users obtain a comparison between predicted and real stay times. This provides valuable insights into the performance of the system, enabling users to make more informed decisions and optimize port operations.

### *4.4. Simulation model*

The simulation model delineates two distinct sets of pathways or routes, catering to vessels and trucks respectively. Vessels originate at the entrance of the bay and navigate towards the anchorage, where they await an appropriate berth to become available. Notably, the Port of Santander is equipped with specific docks designed to handle particular types of cargo and goods. Upon the vessel docking at a suitable berth, the unloading operations commence.

Trucks have designated “spawn” points located based on the main sources of goods. These points can be situated just a few kilometers away from the port or as far as hundreds of kilometers. Each truck is responsible for multiple transshipment operations with the vessel, either loading or unloading operation. Upon arrival at the port, trucks drive to the entrance and queue up in the waiting area. They are only permitted to proceed to the transshipment area when there is sufficient space available for them.

After completing all the necessary operations, such as loading or unloading cargo, the vessel then undocks from the port and sets sail towards the bay’s exit. The departure marks the end of the vessel’s stay at the port.

Figure 4 shows the visualization of the simulated scenario.

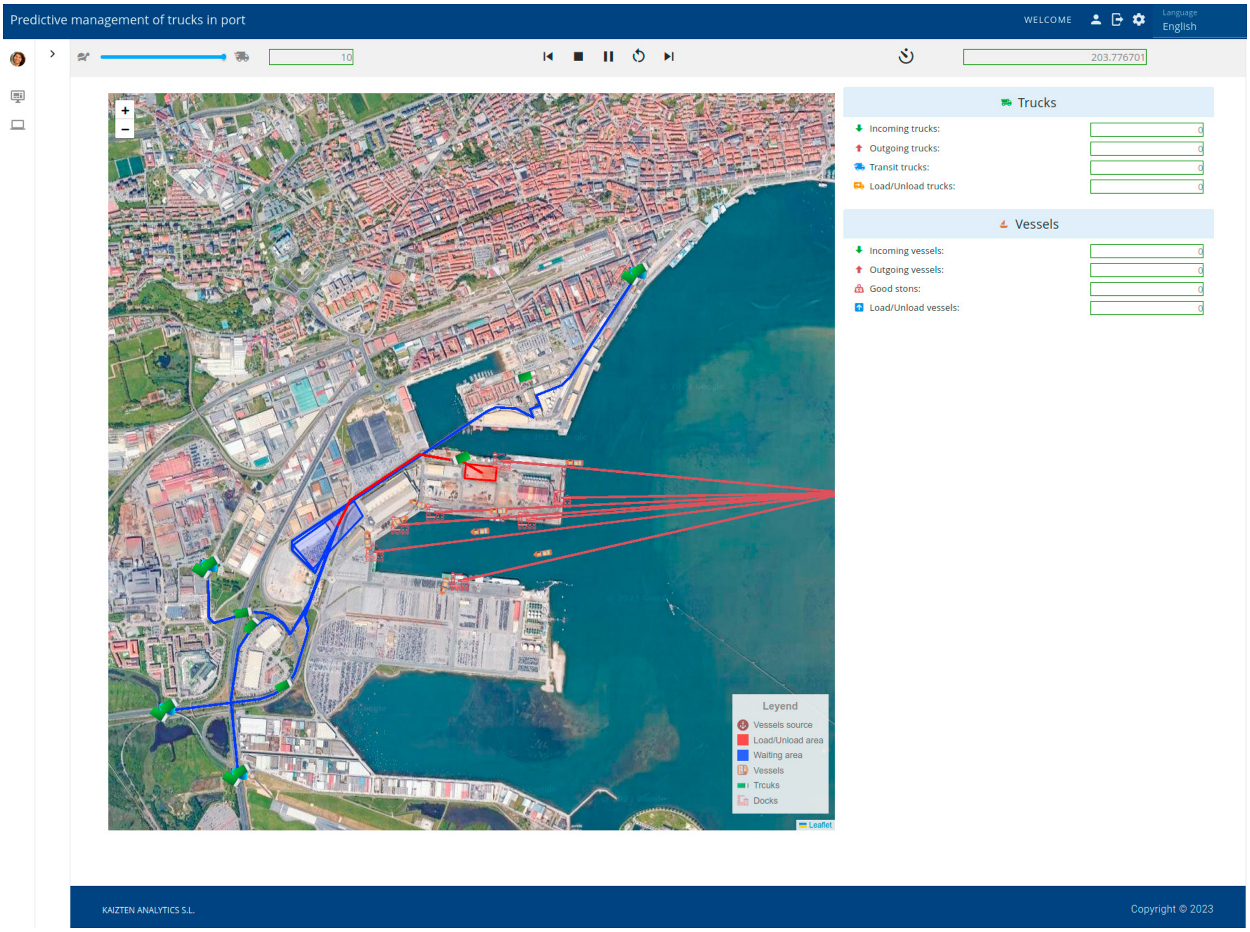



Fig. 4. Simulation model

## 5. Conclusions and further research

This paper introduces a decision-support system based on machine learning techniques, visualization tools and simulation models to manage the stay of trucks at a seaport. It includes several key components. First, data on port activity is collected, such as the number of vehicles entering and leaving, the type of cargo they are handling, and the length of their stay. This data is stored in a data warehouse and processed using machine learning techniques.

The system uses machine learning models to analyze the data and predict the stay of trucks at the port. Different machine learning techniques, such as decision trees and regression, are used to build the models. The models are continuously adjusted as more data is collected and refined to improve the accuracy of the predictions. In addition, the system includes dashboards to display predictions and other important data on port activity. The dashboards provide an overview of the number of vehicles expected to arrive and depart the port, and also show the average time of their stay, among other relevant indicators. Users can adjust model parameters and check how it affects the predictions.

The system has been validated at the Port of Santander and has demonstrated high accuracy in predicting the stay of trucks. The implementation of the system is expected to help improve the port's efficiency and productivity, allowing operators to better plan space and resource utilization and minimize delays in loading and unloading cargo.

Lastly, in terms of future lines of work, it would be important to continue to evaluate and improve the accuracy of the algorithms in different environments. It would also be useful to integrate more variables, such as port capacity and truck loading, to obtain a more accurate estimation. In addition, it would be important to investigate how the machine learning algorithms and simulation models can be integrated into management systems to optimize port productivity. Overall, this study opens the door for further research in the application of decision-support systems in port management and logistics process optimization.

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