PREDICTIVE SIMULATION OF ONSHORE POWER SUPPLY (OPS) REQUIREMENTS FOR PORTS

Raul Redondo [(1)], Raul Atienza [(2)], Jose R. Iribarren [(3)], Arturo Medio [(4)] and Luis Ulla [(5)]

(1) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, raul.redondo@siport21.es
(2) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, raul.atienza@siport21.es
(3) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, jose.r.iribarren@siport21.es
(4) ETSIN Polytechnic University Madrid, Spain, arturo.medio.yanez@upm.es
(5) ETSIN Polytechnic University Madrid, Spain, luis.ulla@alumnos.upm.es

Keywords: OPS, AIS data, traffic forecast, power demand.

1. **ABSTRACT:** Port infrastructure development projects require reliable data for the transition into "smart ports". The purpose of Onshore Power Supply (OPS) is to connect the ship to the electricity grid, reducing CO_2 emissions and noises at port areas. In order to comply with governmental orders, ports have to be able to fulfill 90% of the electricity demand of container ships, passenger ships and ro-ro vessels by 2030. Nevertheless, there are still barriers to the development of this technology, as the installation requires a large investment, renewal of the fleets and available substations near ports. A methodology developed by Siport21 is described using a mathematical model of traffic forecast, based on statistical methods and simulation techniques. As a result, it helps ports in decision-making about the infrastructure required by the OPS technology. The tool considers the terminals of the port and traffic data based on Automatic Identification System (AIS) information to determine the power demand requirements by following the "4th IMO Greenhouse Gas Study" for ships power consumption.

2. INTRODUCTION

Cold ironing or Onshore Power Supply is a new development and requirement for ports due to the present situation and legislative framework in the maritime transport. This is currently undergoing a period of change due to regulations implemented by the International Maritime Organization (IMO) and other governmental organizations regarding CO_2 emissions reduction. In 2021, the European Union launched 'Fit for 55', a package of measures with the aim of reducing greenhouse gas emissions by 55% compared to 1990 levels. One of these regulations state that European ports must ensure by January 1, 2030, sufficient shore-side electrical power to meet a high percentage of demand based on their average annual throughput of container ships, passenger ships and ro-ro vessels.

OPS provide significant benefits (emissions and carbon footprint reduction, elimination of noise and vibrations, less wear and tear on auxiliary engines, increased use of renewable energies in maritime transport, etc.). However, there are still barriers to the development of this technology. The main reasons are economic as these installations require a large investment.

Siport21 has developed a methodology to define the sizing and optimization of OPS facilities in ports. It is based on statistical methods and Montecarlo simulation techniques, providing an estimate of hourly electricity demand over the course of a year associated with probability levels. The model allows reproducing the movements of ships in a terminal considering their specific characteristics and port infrastructure. As a first step, the model is calibrated against real AIS data, the next step is defining the port terminal with detailed data. Once the model is defined, alternative scenarios are studied to accomplish with the future demand of maritime traffic. This methodology will help ports have probability-based estimates and will therefore be essential for decision-making, evaluating the cost-benefit of the investment and the total power to be installed.

This paper will show the results of the analysis developed for a practical case, in which the sensitivity to the different hypotheses and variables involved in the problem can be appreciated and how a certain growth in the transformation of ships to be able to use OPS systems could affect the phased OPS investment in ports. A port which already defined its OPS capacity will be used as an example for calibration and comparison purposes with the methodology developed in Siport21.

3. METHODOLOGY

The methodology to address the required power demand for a specific port of terminal is based on a traffic flow simulation model which allows to understand the traffic movements per terminal in the port, and therefore their required power demands for connection to the local grid.

This study starts therefore with de AIS data analysis, allowing an accurate quantitative description of traffic movements in the port (type of vessels, number, size and draft, scheduled calls, berth occupation, etc.). Given the enormous volume of data, the analysis is based on Big Data, Data Analytics and Data Viz techniques (algorithms used to identify space-time relationships between the different traffics and representation methods).

The AIS data analysis allows the definition of most of the inputs required for the accurate building of the traffic simulation model. Using probabilistic methods based on time at berth, arrival frequency and sizes, allows a predictive simulation model in connection to the OPS.

Port infrastructure definition is the other input required in the model building. Each terminal is associated with a cargo type and have their infrastructure defined (length, draught, number of cranes, storage capacity, etc.).

Once all information is known the model is built, representing the digital movement so the port area, where port data definition represents the static element of the model and the ship movements the dynamic part.

Once the model is built, it is calibrated against real AIS data to check the model quality and its resemblance to the reality which intends to represent. Ultimately, future scenarios are described and quantified. Those scenarios represent the traffic evolution as well as the evolution of the port area and infrastructure based on port masterplan, therefore, the dimensions of the OPS are not done for current port and traffic, but for the future requirements.

To follow the methodology, a base case to derive the power demand is presented. For comparison, the example relates to a real port which has already defined its OPS capacity and has a well-known infrastructure. A deep analysis of the type of vessels with arrival at the port and their facilities is important to check compliance with 'Fit for 55'.

3.1 AIS data analysis

The AIS system allows the identification and tracking of ships from other ships, or coast stations. This system is based on a device installed on board that continuously and automatically transmits information. It allows other vessels in the area or onshore stations to identify their position, the state of the ship and movement parameters. The AIS emits messages with a variable period depending on the navigation status.

The AIS has been developed under the auspice of the International Maritime Organization (IMO) and its installation and use in ships is subjected to the SOLAS Convention (Safety of Life at Sea), compulsory since December 31, 2004. The vessels obligated to incorporate these devices are:

- All vessels on international voyages with a gross tonnage (GT) greater than or equal to 300.
- Al vessels on non-international voyages with a gross tonnage (GT) greater than or equal to 500.
- All passenger ships regardless of size.

Once the quality and the reliability of the AIS data has been verified, different variables are analyzed to get to know the behavior of the vessels in the port. This will be used as input data in the simulation model.

The main study case is the analysis of ships at berth with some of the study variables listed below. The target vessels are container ships, passenger ships and ro-ro vessels.

- Type and size of vessels according to the cargo that access each terminal
  Figure 1 shows the number of vessels per year according to cargo and length for the vessels in the study case.

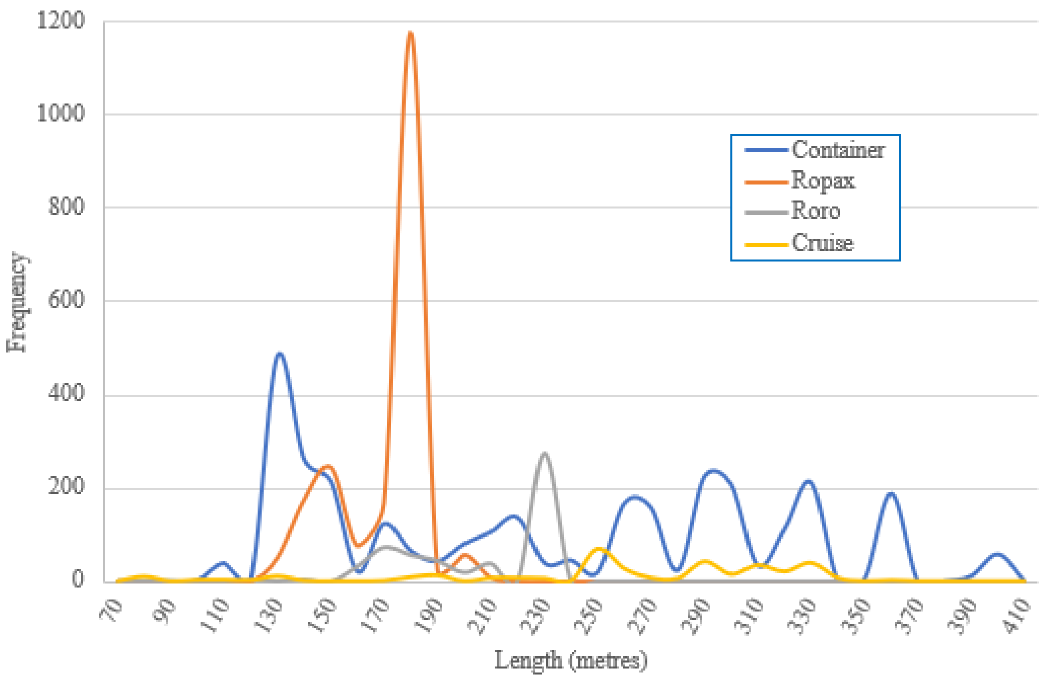

Figure 1: Vessel Size Depending On Cargo. Source : Siport21

- Occupancy levels of the terminal.
  Figure 2 shows the occupancy based on the length of the terminal studied. The level of occupancy is set close to 50% of the terminal and the values are quite regular during a year not depending at all in seasonality.

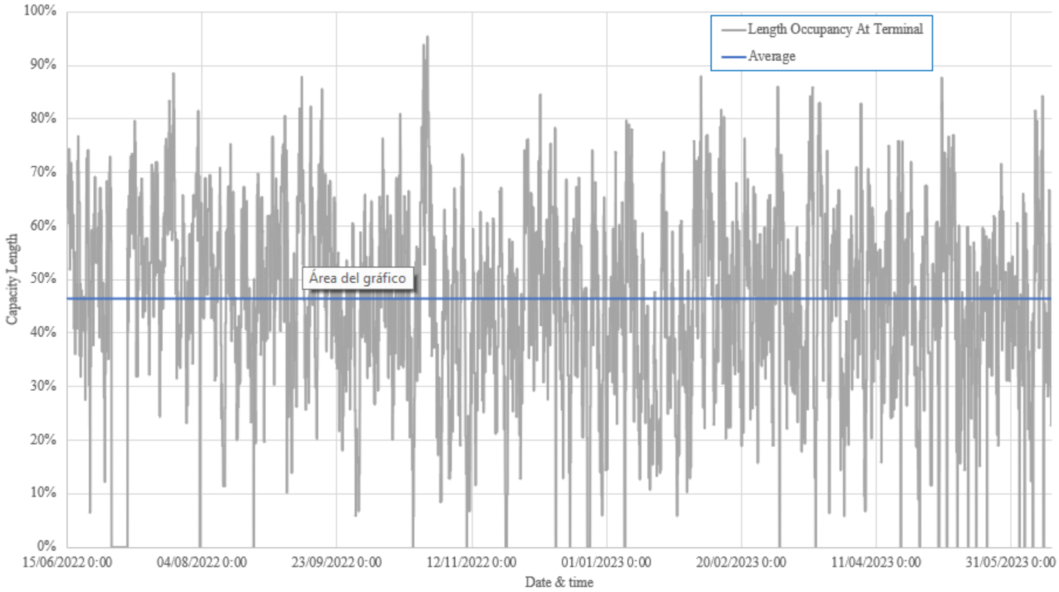

Figure 2. Occupancy Level At Terminal. Source: Siport21

- Time spent at berth
- **Figure 3** shows most vessels spend less than 48 hours in port. There is no linear relationship between these variables.

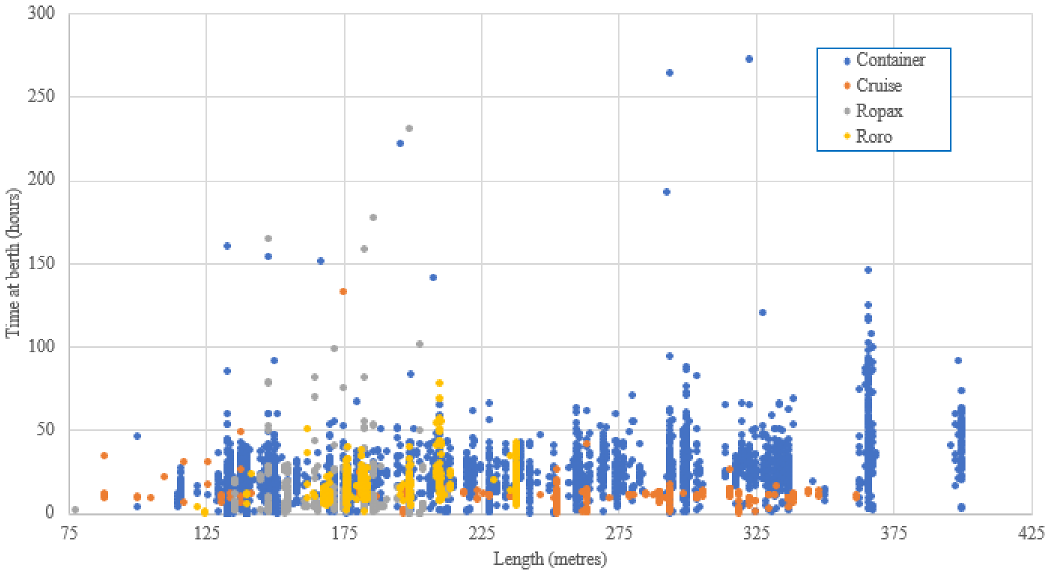

Figure 3. Time At Berth Depending On Cargo And Size. Source: Siport21

The result of the AIS data analysis can be collected in a wide variety of graphs depending on the purpose of the analysis. A series of KPIs (Key Performance Indicators) should be defined to facilitate decision making and understanding the results of the model.

For the particular case of the OPS definition, AIS data is basically used to derive the input data and the statists of the dynamic part of the traffic model which will be built. Where ships data (type, size, frequency, distributions and time and berth) is key to understand the power demand for each individual ship, and therefore, for the complete port area.

3.2 Auxiliary engine power

Based on AIS data and with a reliable data base, a series of power demand values are obtained. Following the Fourth IMO Greenhouse Gas Study allows the model to obtain the auxiliary power demand depending on the vessel type and its capacity (Cubic Meters for LNG tankers, TEU for container ships, Gross Tonnage for passenger ships and Dead Weight for the rest). There are different power assignments depending on the operational mode. In this case study for power demand, vessels are berthed.

During its time at berth the vessels use their auxiliary engines instead of the main engine to supply the electricity demanded by the equipment, auxiliary engines are also used while loading/unloading cargo. When connected to the local grid, and the OPS; the power demand will be the one which is currently being provided by the auxiliary engines, and therefore, this power is addressed.

According to the Fourth IMO Greenhouse Gas Study, the auxiliary engine and boiler power output follows a decision tree based on installed power given by the main engines:

- When the main engine power is between 0 and 150 kW the auxiliary engine and boiler are set to zero.
- When the main engine power is between 150 and 500 kW then the auxiliary engine is set to 5% of the main engine installed power while the boiler power output is based on tabulated values.
- When the main engine power is larger than 500 kW then the auxiliary engine and boiler values are tabulated.

Following these guidelines and with the information obtained from the AIS data, an example of the power demand, for a year-period time, which would have been required for a specific terminal, as shown in **Figure 4**.

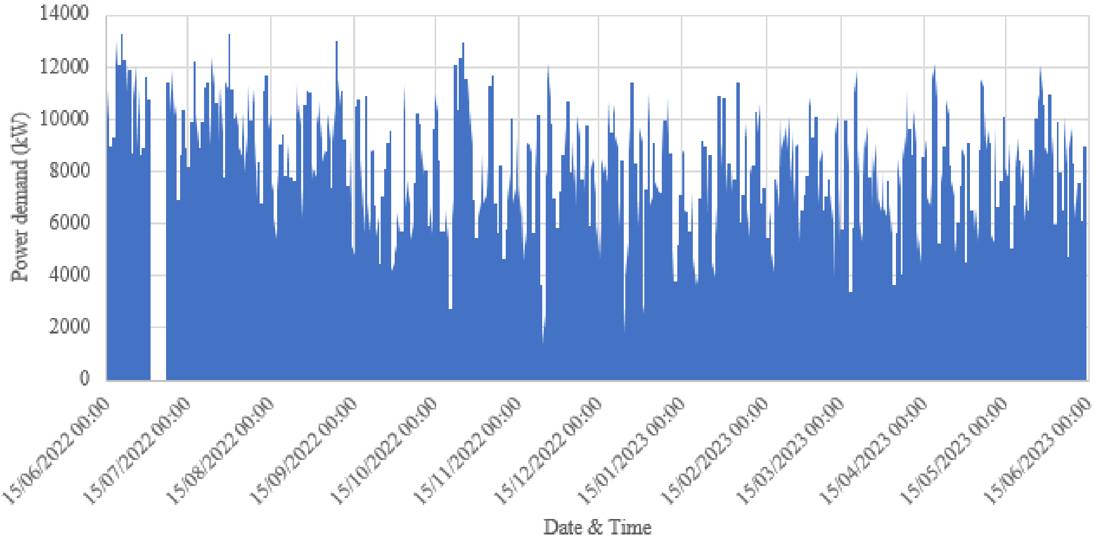

Figure 4. Power Demand By Container Ships In A Year-Period Time. Source: Siport21

3.3 Definition of Key Performance Indicator (KPIs)

In order to facilitate decision-making, a series of key indicators are defined which will allow different future scenarios to be compared with the current situation. KPIs must be aligned with the objectives and particularities of the project. In addition, the same indicators will serve as basis for the calibration process of the maritime traffic model.

In this study the indicators are those referred to the use of the terminals related to the efficiency of the port. There are other indicators such as the number of adapted vessels.

Some examples are listed below:

- Related with the use of the terminals: time ships are berthed and the gap between arrivals are important indicators. These KPIs, combined with the vessel occupancy at the dock, provides information for the capacity and efficiency of the terminals.

Based on **Figure 5** an estimate of terminal occupancy can be done.

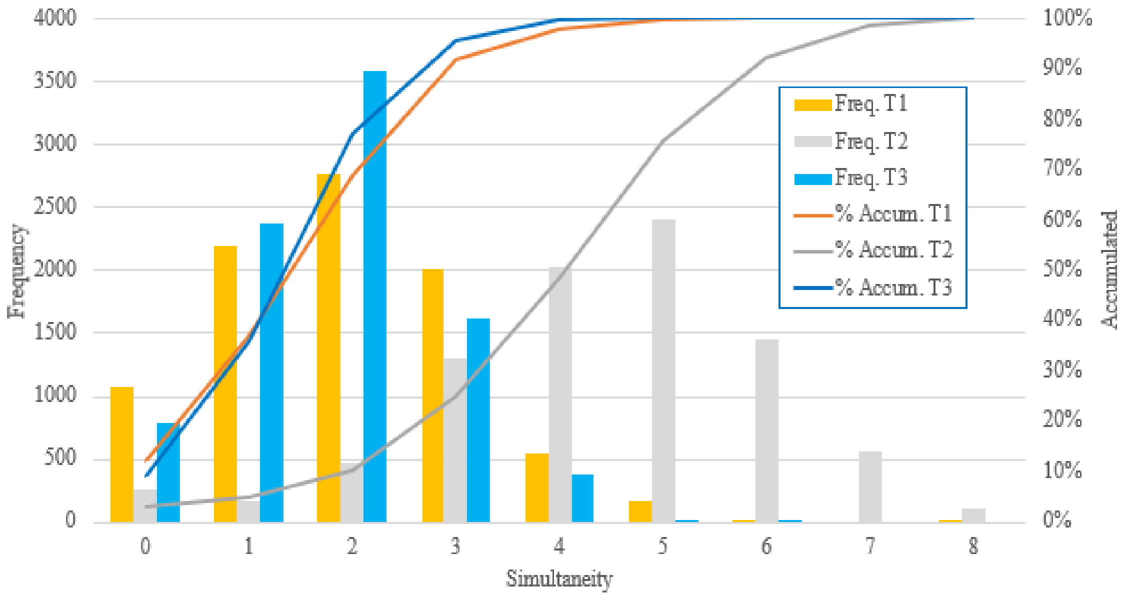

Figure 5. Simultaneity at Container Ship Terminals. Source: Siport21

With **Figure 6** showing the frequency of ship arrivals, combined with the figure just above, an idea of traffic flow at the port can be made to introduce into the model.

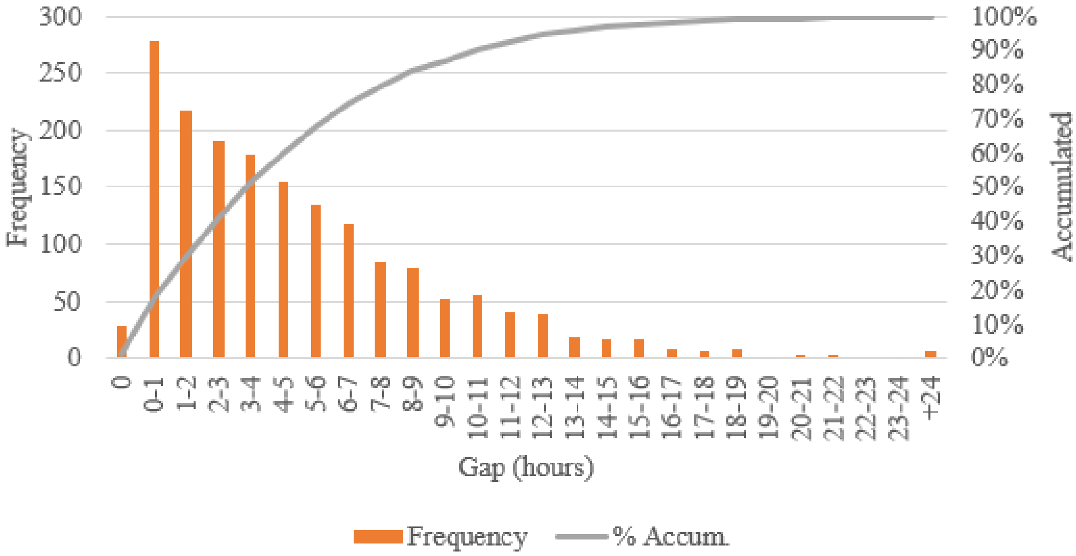

Figure 6. Gap Between Arrivals At Terminal. Source: Siport21

- Related with the power demand: depends on the vessel. It is a very important indicator for decision-making about the substations of the port. As shown in **Figure 7**, a first idea of the average consumption and peaks can be estimated.

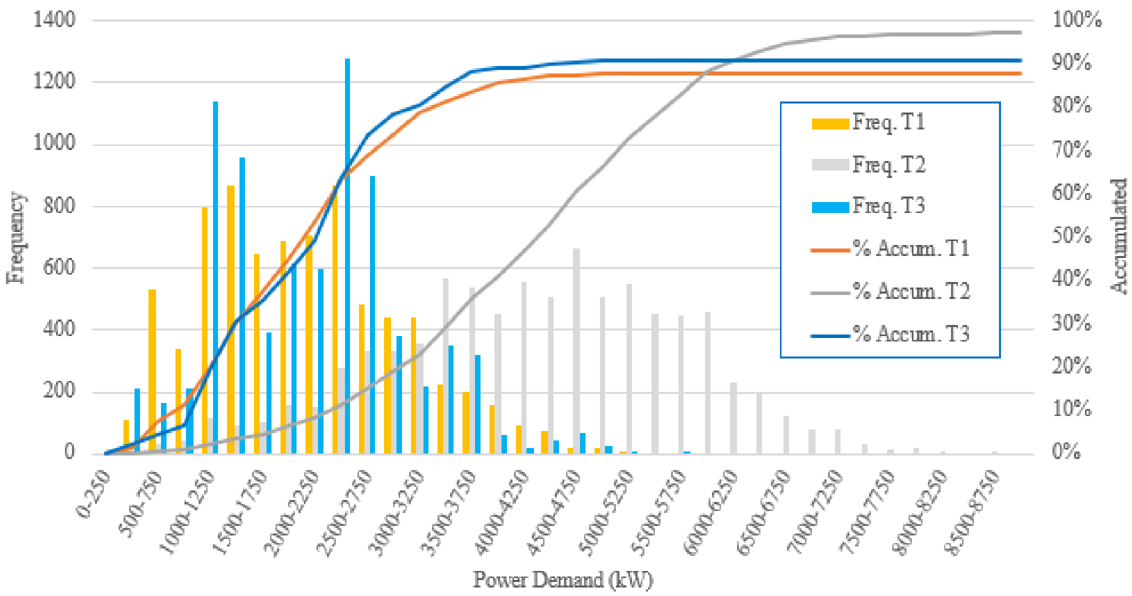

Figure 7. Power Demand at Container Ship Terminals. Source: Siport21

- Related to the economic income: given the time at berth, known the electricity fare and adding the management of the technology by the operators, the economic income can be estimated.

- Related to the efficiency of the OPS technology: less wear and tear on auxiliary engines, emissions and carbon footprint reduction (this can be estimated in the port area as well), and elimination of noise and vibrations.

3.4 Model building

The model building consists of defining the elements taking part in the connection to the OPS technology to the vessels at the port. The model consists of probabilistic distributions based on real AIS data to create random data close to the reality.

The list of elements is listed below:

- Vessels: for this study case, the model needs the length and the draught of the vessel to create a random sequence of arrivals to the dock, as well as a dock dwell time as close to reality as possible. The power demand is linked to the random vessel size and type. The number of ships generated depends on the arrival times defined by the KPIs.
- Port area and terminals: areas where vessels remain for a determined time according to the operations of loading/unloading or refueling, before starting the departure maneuver. Terminals are limited by its length and draught. A maximum number of vessels can remain in terms of length. The gap between vessels must be considered. The terminals are the points where measurements are taken to estimate the power demand and define the substations capacity for the OPS.
- Environmental conditions: such as wind, tide or visibility conditions are described in this module, representing the local climate.

3.5 Simulation

Once the elements of the model have been defined, the simulation process starts by generating a random vessel and keeps creating new vessels with a gap between arrivals to the port defined by statistical distributions based on AIS data. After the generation of each ship, a short simulation is done to recreate the channel navigation based on the speed of the vessel and the restrictions defined. Then, a series of questions in the following order are asked:

- Terminal according to the cargo of the vessel: depending on the cargo and the size of the vessel, a terminal with the appropriate infrastructure is assigned. The ship will go across the navigation channel belonging to the terminal.
- Terminal depending on the draught: terminals have a determined draught. The vessel must have a smaller draught than the terminal.
- Terminal depending on occupancy: depending on the size of the vessel, the occupancy level must be considered, terminals have a limited length. The total length is reduced due to the gaps between vessels for minimum safety distance. Regarding the OPS connection, each terminal has a defined capacity that cannot be exceeded to comply with governmental orders.
- Docking available: the terminal can be distributed in different docks. The same question of the occupancy of the terminal is set out for the docks. In case the docks are full, the vessels are directed to the anchorage area before arriving at the port.

Other restrictions can be considered by adding a waiting point (anchorage area) in the system where vessels can remain until the conditions come back to normality or, the dock is available.

These series of questions are asked in the entrance of each vessel. Once the vessel finishes at its berth, the vessel waits at its dock until the exit channel is clear before leaving the port.

Once the process is built, the calibration is carried out by running the models in an iterative process of simulation (analysis of results) adjustment until reaching results close enough to reality.

The calibration process is always carried out based on a real scenario, from which information on the behavior of ships berthed is available with an adequate level of detail and accuracy.

The level of detail required to achieve reliable results is based on the analysis of the AIS data. However, there is some information that cannot be extracted from its analysis, such as actual draft or the causes of waiting events.

3.6 Alternative scenarios assessment

In general, the new alternative scenarios of interest will be those which have an impact on current traffic flow. These include an increase in traffic volume, new traffic demand which would require changes in port infrastructure (new terminals), new regulations (minimum safety distance between vessels, crossing in the channel, bunkering, …), larger vessels in terms of length or capacity with a new power demand, reduction of the times at berth, etc.

Once the model has been built and calibrated, the results are then compared to real AIS data. The results of the simulation are used in comparison with the KPIs previously defined of the alternative scenarios. In the model building phase, it is possible to adapt the model to the predicted forecast by adding various changes to assess their impact on the traffic behavior by adding new variables and correlations.

In order to find the best fit, each KPI is compared against real data using different distributions such as, gaussian, beta, gamma and erlang, with the purpose of minimizing the quadratic error. The density function is used for comparison, as it is more visual than the distribution function. An example is shown in **Figure 8** for the gap between arrivals at the docks.

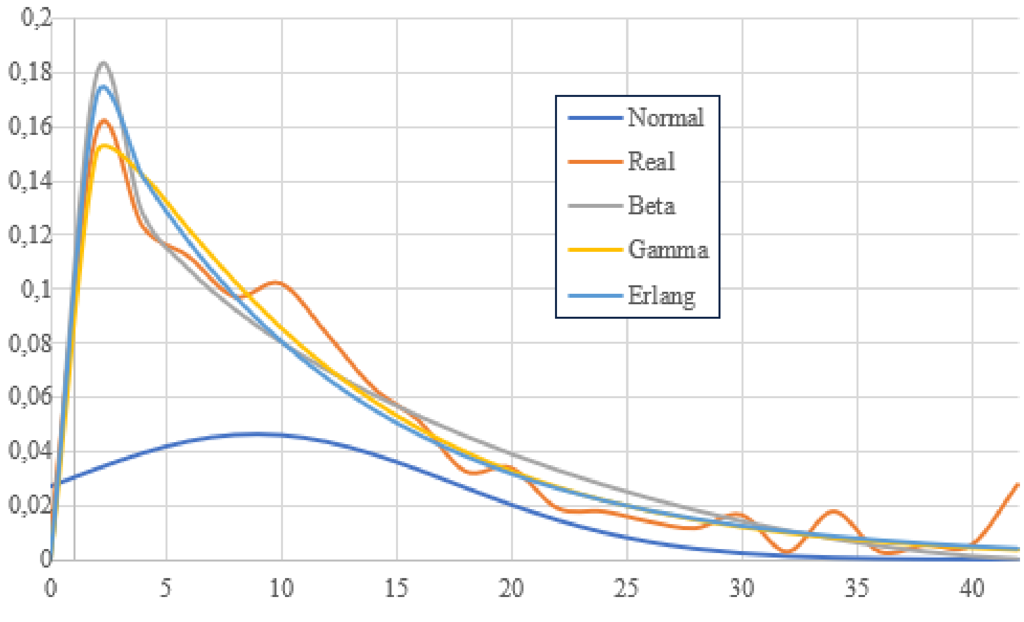

Figure 8. Search Of The Closest Fit Distribution. Source: Siport21

The traffic volume for future scenarios is defined by forecast studies. Historical port traffic data, new port infrastructures, new regulations, shipping lines traffic trends and others, should be considered to define new variables to calibrate the model.

The objective is to achieve the closest fit to reality, which means different scenarios must be analyzed to check that the simulation is adapted to the KPIs and the predicted forecast. The traffic volume for the analysis of those future scenarios is defined through forecast studies of the cargo managed, port infrastructure plans and global market demand.

In **Figure 9** is shown the prediction that the tool proposes based on historical data for a year-period time.

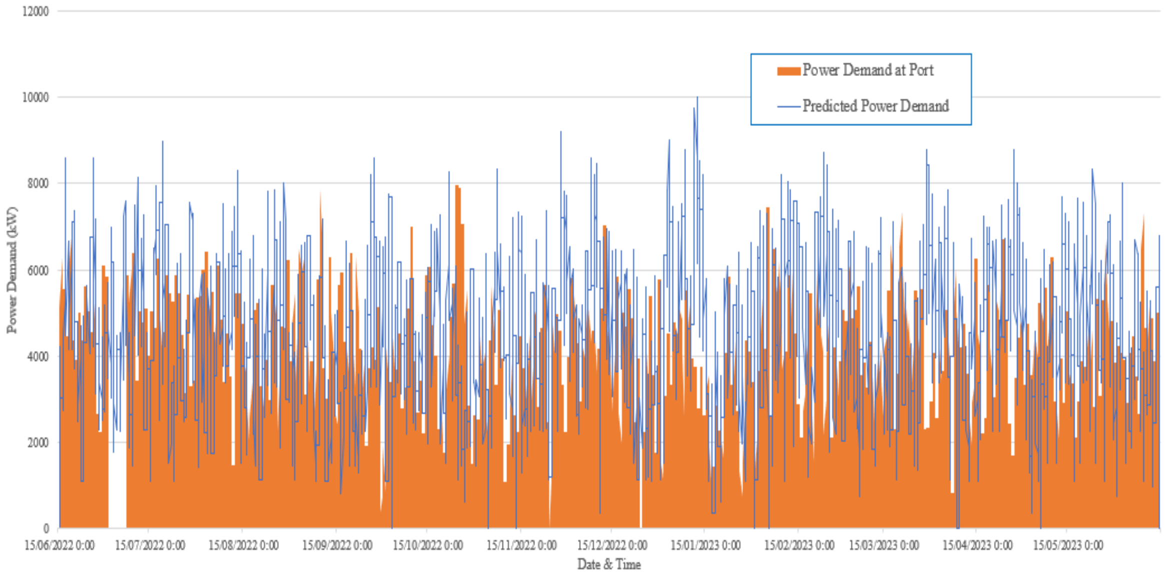

Figure 9. Power Demand Forecast At Container Terminal Based On Historical Data. Source: Siport21

In order to comply with governmental orders, ports have to be able to fulfill 90% of the electricity demand of container ships, passenger ships and ro-ro vessels. Using the mean value for a year-period of time and the deviation of the collected power demand values, the tool can predict the OPS capacity in order to fulfill the percentage required by the pack of measures launched in 'Fit for 55'.

Table 1 shows the power to be installed for the OPS according to the percentage of demand the port cover wishes to cover at the terminal. It is possible to have more than one OPS connection point.

Table 1. Predicted Power Demand to comply with Different Percentage in kW. Source: Siport21

Environment	*Mean Power*	*Deviation*	*99%*	*95%*	*90%*	*85%*
Port	4109	1553	7720	6662	6098	5718
Simulation	4497	1681	8407	7262	6651	6239

The analysis of several traffic volume allows to determine the capacity of a given infrastructure scenario, such as maximum number of vessels that can access the system. The purpose of this study is to estimate the power demanded by vessels to estimate the capacity of the OPS and the substation nearby that will cover this power demand.

Based on the Fourth IMO Greenhouse Gas Study, the shortest power demand by a container ship is 370 kW and the largest 1400 kW. Based on the values of above table, the difference of the average power at the port and the simulation, is the range between the minimum and the maximum range value set by the IMO Study.

4. CONCLUSIONS

This paper presents the methodology to assess the required power demand of port areas and terminals, and, based on the results, understand which requirements must be considered by the port and which percentage of the power demand they can accommodate. As designing for peaks, will lead for over-investments and over-designed systems, which will only be used fully few day per year, and it would be more likely to design and invest for a minor fulfilment of the power demand, understanding that in some cases, ships could be required to wait due to the non disponibility of OPS connection due to grid limitations.

5. REFERENCES

[1] (EMSA), European Maritime Safety Agency. «Shore-Side Electricity: Guidance to Port Authorities and Administrations.» Part 1: Equipment and Technology. Lisbon, 2022.
[2] (EMSA), European Maritime Safety Agency. «Shore-Side Electricity: Guidance to Port Authorities and Administrations.» Part 2: Planning, Operations and Safety. Lisbon, 2022.
[3] (IALA), International Association of Marine Aids to Navigation and Lighthouse Authorities. «Establishment of AIS as an Aid to Navigation.» *Edition 1*, December 2008: Guideline 1062.
[4] (IALA), International Association of Marine Aids to Navigation and Lighthouse Authorities. «Management and Monitoring of AIS Information.» *Edition 1*, December 2005: Guideline 1050.
[5] (IMO), International Maritime Organization. «Fourth IMO Greenhouse Gas Study.» Estudio, London, 2020.
[6] (IMO), International Maritime Organtization. «Third IMO Greenhouse Gas Study.» Estudio, London, 2014.
[7] (PdE), Puertos del Estado. «OPS Master Plan for Spanish Ports.» Estudio, España, 2021.
[8] (SERGAS), Servizo Galego da Saude. «Epidat4. Ayuda de Distribuciones de Probabilidad.» Capítulo 13. Octubre 2014.
[9] Alzate Castro, Wilmar Alexander, y Erika Janeth Salazar Jiménez. «Simulación Monte Carlo: Análisis de una Herramienta para la Proyección del Estado de Resultados. Un estudio de Caso.» s.f.
[10] LLC, Starcrest Consulting Group. «Port of Los Angeles. Inventory of Air Emissions.» Estudio, Los Ángeles, 2021.
[11] Moreno-Gutiérrez, Juan. *Methodologies for Estimating Shipping Emissions and Energy Consupmtions: A Comparative Analysis of Current Methods.* 2015.
[12] Tortosa Solvas, Enrique, y Juan F. Rebollo Lledó. «La Red AIS Portuaria. La Tecnología AIS Aplicada a la Explotación Portuaria y a las Ayudas a la Navegación.» En *Puertos nº 158*, 9-21. 2010.
[13] Trozzi, Carlos. «Emission Estimate Technology for Maritime Navigation.» *US EPA 19th International Emission Inventory Conference.* 2010.