Sizing of Cargo and Passenger Capacity of Ro-Ro Passenger Ships

Bernardo Silveira de Almeida

Thesis to obtain a Master of Science Degree in

Naval Architecture and Ocean Engineering

Examination Committee:

President:	Prof. Carlos Guedes Soares
Supervisor:	Professor Manuel Ventura
	Professor Luiz Felipe Assis (UFRJ)
Members:	Professor Tiago Santos

December 2020

TÉCNICO LISBOA

Sizing of Cargo and Passenger Capacity of Ro-Ro Passenger Ships

Bernardo Silveira de Almeida

ACKNOWLEDGEMENTS:

I hereby express my gratitude first to my family who always supported me and forced me to my best, without them I would not be finalizing this thesis project to a master's degree in Lisbon. Especially to my parents, my mother Lisy Lopes Silveira, my father Erenilton Dias de Almeida Jr, and my little sister Ana Catarina Silveira de Almeida.

There is also the need to emphasize the importance of high school friends, that even with so much distance and time behind us, remain my best friends. A greeting to my university friends from Brazil and Lisbon, especially my Italian-Brazilian family in Portugal, who welcomed me when I needed and left a footprint in my life forever. Added to them, the work colleges that built me as a professional, preparing me for this new step of my life, in particular to Dra. Ágata Nicolau, Dr. Rui Mendes, and Dra. Denise Matos, without whom I would not be able to stay in Portugal for the whole master's program.

I would like also to express my gratitude to professors Prof. Dr. Manuel Ventura and Prof. Dr. Tiago Santos for guiding and tutoring me in an exemplary way during the development of this work. A special acknowledgment to Eng. Nuno Jesus who helped me with data and information for the project.

Lisbon, December 2020

Bernardo Silveira de Almeida

ABSTRACT:

This thesis is focused on the identification, study, and implementation of new and existing methodologies presented in the existent literature for the sizing of the capacity of a Ro-Pax ship, with the definition of its main particulars and forecasting the costs related to this type of operation, using the predefined Portugal-Madeira route's demand as a base point. This work is built upon statistical historical data and methodologies for sizing Ro-Ro and Ro-Pax vessels. Through a numerical tool, the specific demand for the desired scenario is identified and a ship is sized, showing all the costs and investments needed to operate this route under these circumstances.

The seasonality of the route is an aspect already known by several players of the market but never studied qualitatively. However, this project comes in an attempt to do to identify and quantify this phenomenon making possible the development of a viability analysis of the route. Existing studies analyze the feasibility of certain European Short Sea Shipping (SSS) routes with a predefined ship to operate them. This project comes oppositely, trying to size a ship, evaluating the new building investments, and trying to simulate all the costs related to the operation studied.

The tool simulates the route's yearly scenario of demand, including its seasonality phenomenon, and using newly developed and already known formulae to define the main features and size of a ship. Finally, the sizing method created in the project is tested in the case study, using the previously operated vessel as a comparison, analyzing the differences between the ship-generated and the one used in the route. More than this, in the case of study, it is also analyzed the best capital investment option between chartering the operated vessel or building a new one.

Thus, the conclusions become clear that only the operation of the route can bring profits to the company but adding the capital investment to the cash flow of the operation, we find a loss greater than the profits throughout its twenty years. Meaning as pointed out by other authors that, without external funding of the operation, turns out to be unprofitable to operate the SSS route.

This thesis ends with comments and recommendations, especially regarding the improvement of the method and future steps on the development of the numerical tool.

Keywords:

Short Sea Shipping, Ro-Pax ferry modeling, Investment Analysis, Liner Shipping, Transportation demand, Cost models

RESUMO:

Esta tese está centrada na identificação, estudo e implementação de metodologias novas e existentes apresentadas na literatura existente para o dimensionamento da capacidade de um navio Ro-Pax, com a definição de seus principais detalhes e previsão dos custos relacionados a este tipo de operação, utilizando como ponto base a demanda pré-definida da rota Portugal-Madeira. Este trabalho é construído sobre dados históricos estatísticos e metodologias para o dimensionamento de embarcações Ro-Ro e Ro-Pax. Através de uma ferramenta numérica, identifica-se a demanda específica para o cenário desejado e dimensiona-se um navio, mostrando todos os custos e investimentos necessários para operar esta rota sob estas circunstâncias.

A sazonalidade da rota é um aspecto já conhecido por vários agentes do mercado, mas nunca estudado qualitativamente. Entretanto, este projeto vem na tentativa de identificar e quantificar este fenômeno, tornando possível o desenvolvimento de uma análise de viabilidade da rota. Os estudos existentes analisam a viabilidade de certas rotas de Short Sea Shipping (SSS) européias com um navio pré-definido para operá-las. Este projeto vem em sentido contrário, tentando dimensionar um navio, avaliando os novos investimentos em construção e tentando simular todos os custos relacionados com a operação estudada.

A ferramenta simula o cenário anual de demanda da rota, incluindo seu fenômeno de sazonalidade, e utilizando fórmulas recentemente desenvolvidas e já conhecidas para definir as principais características e tamanho de um navio. Finalmente, o método de dimensionamento criado no projeto é testado no estudo de caso, usando como comparação o navio anteriormente operado, analisando as diferenças entre o navio gerado e o utilizado na rota. Mais que isso, no caso do estudo, também é analisada a melhor opção de investimento de capital entre o afretamento do navio operado ou a construção de um navio novo.

Assim, as conclusões ficam claras que somente a operação da rota pode trazer lucros para a empresa, mas adicionando o investimento de capital ao fluxo de caixa da operação, encontramos uma perda maior do que os lucros ao longo de seus vinte anos. O que significa, como salientado por outros autores, que, sem um financiamento externo da operação, acaba sendo pouco rentável para operar a rota do SSS.

Esta tese termina com comentários e recomendações, especialmente no que diz respeito ao aperfeiçoamento do método e passos futuros para o desenvolvimento da ferramenta numérica.

Palavras-chave:

Transporte Marítimo de Curta Distância, Modelação de ferry Ro-Pax, Análise de Investimento, Transporte Marítimo, Demanda de transporte, Modelos de custos

TABLE OF CONTENTS:

LIST OF TABLES:

LIST OF FIGURES:

ACRONYMS:

APARAM: *Administração dos Portos da Região Autónoma da Madeira, S.A.*

Cb: Block Coefficient

CRF: Consolidated Retirement Fund

DWT: Deadweight

ENM: *Empresa de Navegação Madeirese*, Lda

EU: European Union

FR: Freight Rate

FRS: Fast Reliable Seaways

GT: Gross tonnage

HFO Heavy Fuel Oil

IMO: International Maritime Organization

IWW: Inland Waterways

LOA: Length overall

LoLo: Lift-on, Lift-off

MAR: *Registo Internacional de Navios da Madeira*

MDO: Marine Diesel Oil

NPV: Net Present Value

NUTS: Nomenclature of Territorial Units for Statistics

RAA: *Região Autónoma dos Açores*

RAM: *Região Autónoma da Madeira*

Ro-Pax: Roll-on/Roll-off passengers ship

Ro-Ro: Roll-on/Roll-off ships

SFOC: Specific Fuel Oil Consumption

SSS: Short Sea Shipping

TEU: Twenty-foot Equivalent Unit

TMCD: *Transporte Marítimo de Curta Distância*

TUP: *Taxa de uso de Porto*

USD: United States Dollars

SYMBOLOGY:

B – Breadth

B_{DH} – Breadth of the double hull

BMT- Transverse metacentric radius

C_b – Block coefficient

$C_{midship}$- Midship section area coefficient

C_p -Prismatic coefficient

C_{wl} – Waterplane area coefficient

c_f – Friction coefficient

D – Height up to the weather deck (uppermost continuous deck above the keel)

D_{prop} - Propeller diameter

DWT_{cargo} – Deadweight for cargo

DWT_{pax}- Deadweight for passengers

FB – Freeboard

F_n – Froude's number

F_{side} – Side thrust

GMT- Transverse metacentric height

GT – Gross tonnage

H_{DB} –Height of the double bottom

HP – Propulsive power installed

I_{xx} - Transverse moment of inertia of the water plane

KB – Buoyancy center ordinate

KM – Metacentric height

LCB - Buoyancy center abscissa

L_{ER} – Length of the engine room

L_{FP} – Length of the forward collision bulkhead

L_{OA} – Length overall

L_{fb} – Freeboard length, following IMO definition

L_{wl} – Length on the waterline plane

Lmt – Lanemeters capacity

Lpp – Length between perpendiculars

P_{EL} – Electrical power

P_{side} – Side thruster power installed

pax – Maximum passenger capacity of the ship

R_A- Additional resistance due to model/ship correlation

R_{APP} – Appendage resistance

R_B – Bulbous resistance

R_F – Friction resistance

R_T – Total resistance

R_{TR} -Transom resistance

R_w – Wave making resistance

S_w – Wetted surface

T – Draught

v- Ship's velocity

V_{ER} – Volume of the engine room

W_H – Hull's weight

W_M – Machinery's weight

ρ – Seawater density

$\$P$ – New building price

$\$RV_{scrap}$- Residual Value (scrap value)

$(1 + K_1)$ – Form factor

Δ- Displacement of the ship

∇ - Volume displaced

η_G - Gear Box efficiency

η_H - Hull efficiency

η_M - Shaft efficiency

η_O – Open Water efficiency

η_R - Rotation Relative Efficiency

1. INTRODUCTION

1.1 Background and Motivation

Every thesis has the same aim, to study, understand, and evaluate a certain reality or event, independent of the area of study. All studies are done so the researcher can explain and answer inquiries about a specific topic or phenomenon.

In this context, this thesis aims to understand and analyze the operational feasibility of a marine transportation link between Continental Portugal and the Madeira Island (RAM) using a Ro-Pax vessel - also known as ferry. Therefore, and within the scope of the Master's degree in Naval and Ocean Engineering promoted by Instituto Superior Técnico, it was decided to approach this theme in a more in-depth way, conducting a study as a final master's dissertation.

It is important, before starting, to understand the background that underpins this project. The European Union (EU) has been promoting, since the beginning of the ’90s, more competitive internal supply chains. The aim is to promote the investment in different transportation modes, such as Short Sea Shipping (SSS), inland barge routes, inland waterways (IWW), and freight railways that can be more sustainable than the traditional roadways used until now.

Most of the European imports and exports are carried by roads, which means depending on the origin and the destination, the cargo must cross several borders, many different highways until arriving at its destination, with the risk of delays, higher freight rates, and taxes in the way. In addition, the direct consequences of the use of roadways are the increase of transit of heavy cargo in the roads, degradation of the highways, congestion, and finally, pollution problems.

As a solution to these problems, Ro-Ro ships (cargo or passenger ships) are increasingly being used by European countries, and this type of transportation mode, in most cases, can be classified as a Short Sea Shipping (SSS). SSS is characterized by marine routes between European ports, or between a European port and another non-European port that shares the same waters that surround Europe, such as the ones in the Baltic Sea, Black Sea, and the Mediterranean Sea. In this way, the SSS can be described by a national or international route between two ports. Therefore, the route between mainland Portugal and Spain and its islands in the Atlantic Ocean can be classified as such, being both ports, European ports.

The European SSS routes can be divided into five major regional markets, each with its features: The Black Sea, the Mediterranean, the Atlantic Range, the North Sea, and the Baltic Sea. Figure 1 shows the cargo carried in SSS in their regional markets.

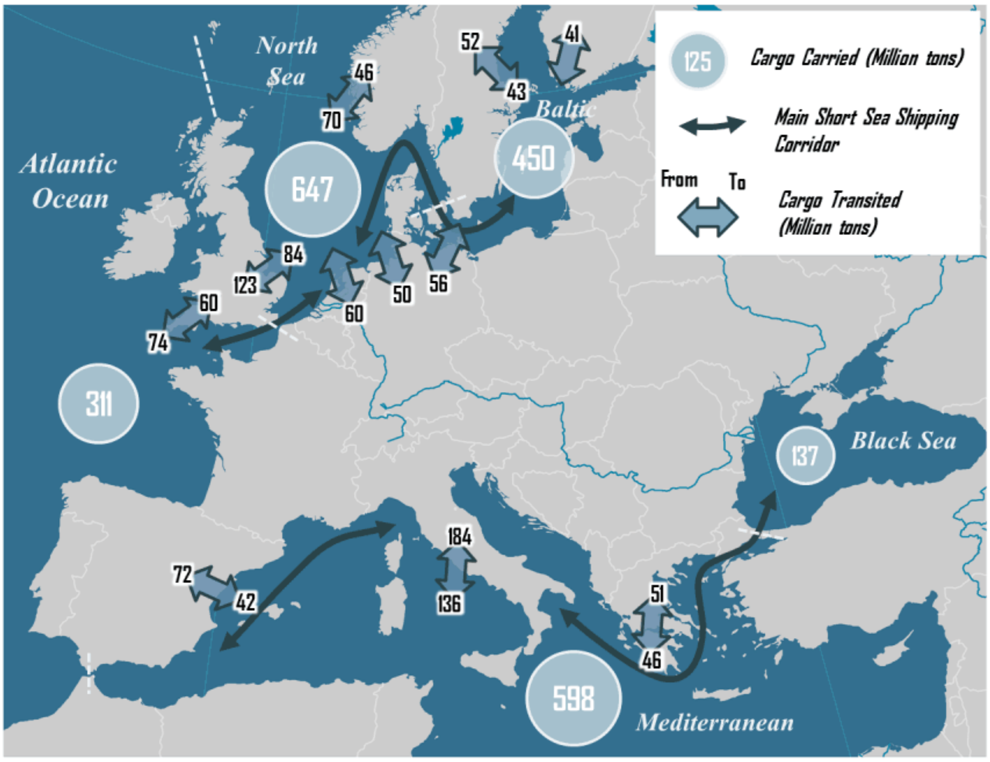


Figure 1 - The European Short Sea Shipping [1]

Another fact that support the importance of this type of study is the policy adopted by European countries and European Authorities to promote the shift of cargo transportation from roads to these alternative ways, by restricting the road transport of cargo. These constraints can vary from bans in respect of driving at weekends, at night, or on holidays, to limitations in the driving hours of the truck driver or the total abolition of truck traffic on some specific roads, leading to an increase in cost to road haulage. According to the European Commission (2011), one of the goals is that 30% of the road transport over 300 km should be shift to other modes by 2030, and more than 50% by 2050.

In these circumstances, it is important to find a more competitive and sustainable alternative transport solution for supplying the European demands between several of its hubs. The SSS presents itself as a solution in terms of transportation cost (linked to economies of scale), in most cases. More than this, for the periphery European countries - this includes Portugal and Spain - the maritime transportation becomes a great solution for carrying big quantities of cargo, avoiding extensive use of the road network of other countries when conveying exports and imports from Central and Northern Europe.

Nevertheless, the SSS solution can present several options of ship's types. Therefore, it is necessary to analyze the most flexible solution in these SSS routes, and for this the Ro-Ro ships have a special role, allowing a decrease of the transit time spent in these corridors in comparison to containers ships, especially regarding the cargo handling procedures, dwell time and, added to these, they present the possibility of carrying passengers. So, this thesis will focus on the Ro-Ro ship for the declared route.

[1] *Source: The Geography of Transportation System, based on Eurostat data*

The connection between mainland Portugal and the RAM, in the past years, was operated by a ship owned by *Naviera Armas*, a Spanish company that operates the ferry between Huelva (Spain) and Canary Islands (Spain). The ship was operated by a Portuguese company, ENM (Empresa *de Navegação Madeirese, Lda)*, in the route studied. The latest ship used is the *Vólcan de Tijarafe*, a Ro-Pax ship with $143\ m$ of LOA and a capacity of $1{,}000$ passengers and 300 cars, with $20{,}500$ in GT. The service did not have a continuous operation in past years, because the chartering company claims that the route does not have enough profit to do so.

In this context, this project aims to develop a numerical model that allows the evaluation of the transportation demand, operating costs, voyage costs and capital costs, and the sizing of a ship for this SSS route. The model may assist the governmental and private entities when evaluating a possible contract to operate in this route. The goal is to provide a complete capital and operational costs forecast when operating in this route, becoming an important tool to evaluate the viability of the trip. Namely, the objective is to determine the most suitable ship's main characteristics for the route, having a freight rate (FR) and the ship service speed, that could express the demand of the RAM in the route, identifying its operating parameters.

This study is going to be done, first using real-life data to stipulate the different demands during the year, taking into consideration the seasonality that has been already identified as a major factor in this route (especially regarding the passengers' demand), creating a method that can prescribe the required size for the vessel to supply it. After that, predict the initial investment for building it, forecasting the capital costs, and calculating the operational costs along its years.

1.2 Objectives

Every research work presents a main objective that determines the motivation of the study and, in addition, this goal is demystified through a list of ambitions, or points that the work seeks to meet. These objectives will determine the lines of research to be developed, adding value to the study, being important topics for the scope of the same.

Not different, the thesis has as **main goal** the identification of the ship's characteristics and the characterization of the costs (capital and operational costs) for a Roll-on/Roll-off passenger ship for a specific rote between Continental Portugal, namely Portimão port, and the Madeira Island, namely Funchal port.

Having in mind this objective, a set of **detailed goals** can be listed:

- Identify and characterize the route, with its restrictions.
- Identify the demand and seasonality during the year of the flow of passengers and cargo between the ports.
- Create a database for Ro-Ro and Ro-Pax ships with different characteristics.
- Create a method for sizing a Ro-Pax ship based on anticipated demand for cargo and passengers.

- Calculate the main characteristics of the vessel defined.
- Calculate capital costs, operating costs, and voyage costs for the specific route.
- Apply all the governmental requirements and allowances for the operation simulation.
- Evaluate the economic feasibility of the route for different scenarios of investments.

1.3 Theoretical Background

Fostering the SSS corridors development, many financing programs have been promoted since 1992, for instance, PACT, Marco Polo I and II, Motorways of the Seas, and TEN-T, according to EFTA (2007). A significant body of literature has reviewed and evaluated the success or failure of many of European SSS routes, identifying its reasons, namely Baird (2007), Styhre (2009), Douet and Cappuccilli (2011), Baindur and Viegas (2011) Aperte and Baird (2013), Ng, Sauri, and Turró (2013), and Suárez-Alemán (2016). All of them recognized that the SSS service operates while it has a financial incentive, and when this one is over, they will disappear shortly afterward.

Deeming the importance of the competitiveness of a sustainable alternative for haulage of goods between diverse countries of Europe, several studies have been done in the past years, trying to evaluate the technical and economic feasibility of intermodal solutions of transportation, including a marine stretch in different specific corridors. For example, many studies have been done between peripheral countries and central and northern Europe, such as Tsamboulas, Lekka, and Rentziou (2015) and Martínez-López, Kronbak, and Jiang (2013), (2015). But these studies typically try to evaluate the feasibility of a solution using a predefined ship with a certain size and capacity.

Santos and Soares (2016) presented a study of a Portuguese case with several scenarios to a roll-on/roll-off ship fleet, considering an intermodal solution comprising Ro-Ro ships and pre and pos road haulage, using a predefined ship fleet to supply the demand in different combinations of ship speed and freight rates. But the model used to take into consideration the ship (or fleet of ships) is available and fit technically to carry out the service, the model does not require the size of the ships or its economic feasibility, it only takes into consideration the shipper view in the approach.

After that, Santos and Soares (2017) also develop a methodology for determining the characteristics of a cargo Roll-on/Roll-off (Ro-Ro) ship and the fleet size required for a given short sea shipping route. The main technical characteristics of the most suitable ship were obtained, the time charter, voyage costs, and revenue are then calculated considering the technical characteristics of each ship. This study took into consideration the shipping companies' perspective in the service. This thesis comes with the same goals but adding the seasonality phenomenon to the demand scenario and considering a different route.

1.4 Structure of the Thesis

The current study presents a methodology to size a suitable ship depending on the demand for cargo and passengers between Portimão and Funchal during a period of operation. The method allows simulating several scenarios and ships and can be used in the future to find the optimal point of operation of the route for the shipping company. Therefore, it is necessary to identify the cost structure, sizing methods, and demand behavior implied in the type of operation of a Ro-Pax, taking into consideration the operational restrictions of the service studied (such as port restrictions, maximum ship size, etc.).

The thesis is organized in the following manner: it is composed of five chapters and respective appendices. Chapter 1 is the introduction, the contextualization, the theoretical background, and the motivation to explain the need for this thesis, including the goals and the structure of the work.

Chapter 2 explains the route studied, the physical characteristics of it. Also including the possible port's profiles, government restrictions for the vessel characteristics for the service, and the assumptions made to create the mapping of the demand used during the development of the work. More than this, the chapter also presents the literature review necessary for the development of the work.

In this way, Chapter 3 explains the Ro-Ro ships, their characteristics, the sizing method used for the project, and the cost structure assumed for the study. With the explanation of the capital costs, operational costs, and voyage costs. Beyond this, the chapter also presents how the methodology is presented as a numerical tool, illustrating all features of the tool.

Chapter 4 presents a case study of the methodology, comparing the results obtained with the real-life operation, trying to obtain the needed corrections for the predictions. Besides that, the chapter also presents the analysis of two different scenarios, analyzing the feasibility of the service in those cases, discussing possible explanations.

Finally, the last chapter outlines the general conclusions of the case study using the developed methodology and the results obtained with it. Furthermore, it explains the extent to which the author recognizes the limitations of the current model and understands in which ways it can and shall be improved in future works.

In the Appendices are presented the list of all the ships listed for the database created with some of its information, the specifications of a generator set assumed, the emails proving the subsidies of the route (in Portuguese, original format), and the detailed global cash flow of the case of study are displayed in the appendixes.

2. THE TRANSPORTATION PROBLEM: FERRY PORTUGAL-MADEIRA

Before starting the study, it is important to understand the route itself, and the historical importance of the region, its features, and the main physical characteristics that may impact decisions on the operational planning of the vessel.

Since its discovery, the Madeira archipelago draws attention because of the appropriate climate for agriculture and the vast natural variety, composed of mountains, cliffs, beaches, sheltered waters, among others. Having different major drivers over the past decades, nowadays, it is most visited because of its natural sightseeing and it is reinforced by the cultural, architectural, and social legacy of the region, that is why tourism became the main economic activity of the RAM.

The Madeira archipelago is located between 30º N and 33º N in latitude, the same as Casablanca, almost 530 nautical miles south-west from Lisbon, $380\ nm$ from the African shore, and $250\ nm$ from the Canary Islands. Being composed of 8 islands and some islets, from those only the 2 biggest are populated (Madeira and Porto Santo), having its capital in Funchal. In the latest reports, the total number of residents is over $250{,}000$ in 2019, precisely $254{,}254$ residents. Figure 2 illustrates the RAM with its main islands and most important cities.

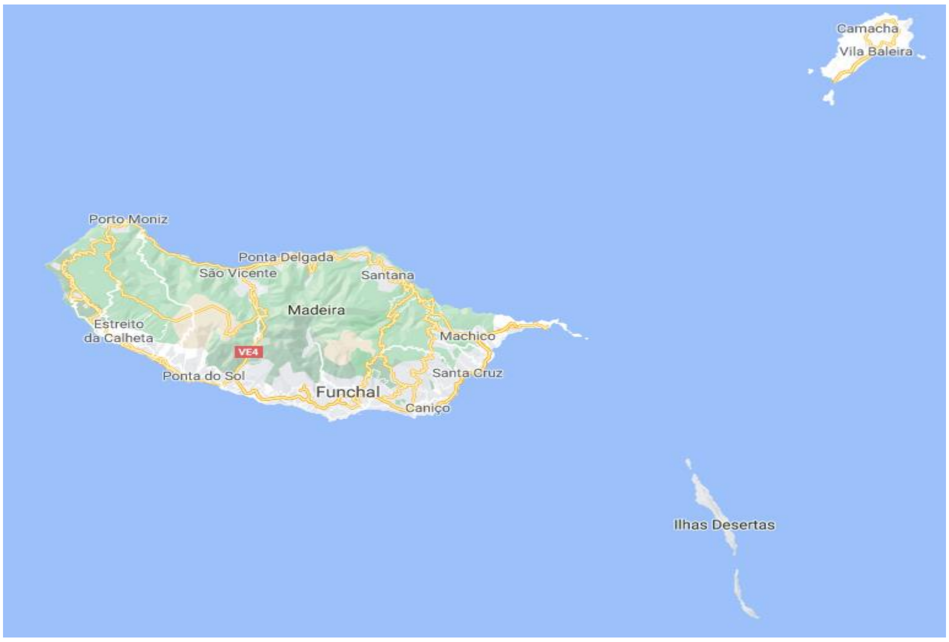


Figure 2 - Map of RAM [2]

The objective of the route will be to link the RAM to the mainland of Portugal, taking into consideration the different possibilities of the route and regarding the infrastructure and superstructure of the different

[2] Source: Google Maps

ports possible. The route chosen was between the port of Portimão and the port of Funchal, the reasons will be explained hereafter.

2.1 Ports description

As said before, many route options can be chosen to connect the RAM to continental Portugal, but many of the available ports in both regions have infrastructure or superstructure inability, which turns the operation very difficult without any capital invested to adapt these ports to the demands of the operation, or even impossible.

Also, it is important to notice that the Portuguese government restricted the port options for the operation of the line. As stated in the Autonomous Region of Madeira Regional Government (2018) the only port in the RAM possible to operate is the port of Funchal, and in the continent, there are the following options:

- Port of Portimão *(Porto de Portimão)*
- Port of Setúbal *(Porto de Setúbal)*
- Port of Lisbon *(Porto de Lisboa)*
- Port of Leixões *(Porto de Leixões)*

In this section, all the possible continental ports will be listed with their most important infrastructures and superstructures that reflect consequences for the ferry operation, namely the terminals and their characteristics. Finally, the Port of Funchal will be presented with its most important characteristics for the operation of the ferry.

- **Port of Leixões (*Porto de Leixões)*:**

The biggest port infrastructure of the north of Portugal, located in 41º 11' N, 8º 42' W, is close to the city of Porto. It has good marine and shore access (roadways and railways), modern equipment, and port management software systems.

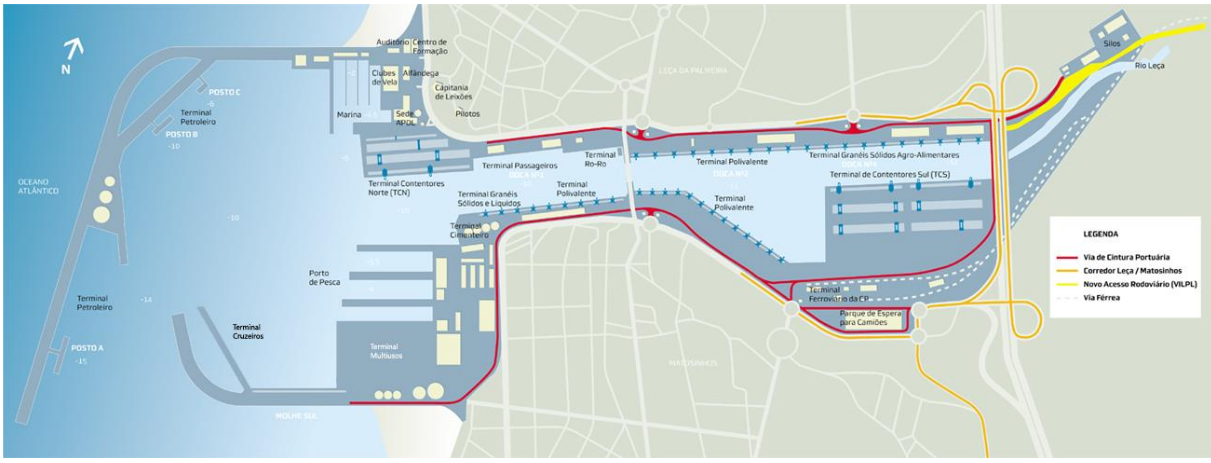


Figure 3 - Map of the port of Leixões [3]

The port is composed of several specific terminals, able to handle a vast range of products, from bulks (dry and liquid) to containers and trucks. About the Roll-On/Roll-Off terminal, is in Dock number 1 north, with a depth of $-10\ m$ ZH with a length of $455\ m$. Also, provides a storage area for approximately 100 trailers and a fixed platform with a maximum width of 22 meters and a minimum width of 11 meters, and a slope of 7.7%.

The port is also composed of a cruise terminal, with a quay of $340\ m$ in length and depth of $-10\ m$ ZH, supporting vessels up to $300\ m$ in LOA. But in this terminal, there is not a Ro-Ro facility, so is not considered in the comparison with the other ports.

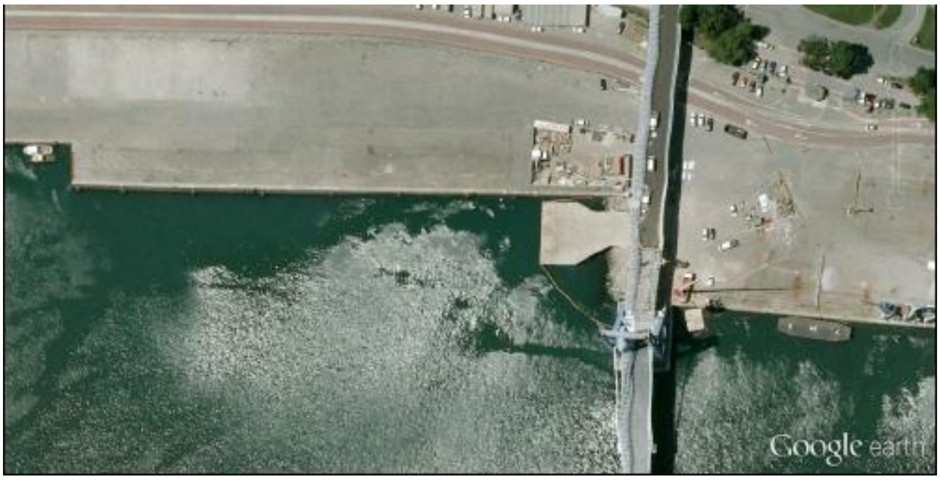


Figure 4 - RO-RO terminal of the port of Leixões [4]

Leixões' port was not selected in the study because of the great distance to the RAM, almost $665\ nm$, increasing the operational costs, especially regarding the fuel costs of the operation.

[3] Source: APDL - *Administração dos Portos do Douro e Leixões*
[4] Source: Google Earth

- **Port of Lisbon (*Porto de Lisboa*)**

The port of Lisbon is a natural port, located at 38º 42' N, 09º 06' W, in the estuary of the Tagus River (*Rio Tejo*), which provides good conditions for different ships to operate. It has railway access, once the port is integrated with the railroad network of the capital of the country, connected also with international railroad networks. The port is composed of 18 different port terminals, from bulk (dry and liquid) to cruise terminals.

The Roll-On/Roll-Off terminal is located in the north face of the port in the *Cais avançado de Alcântara*, which has $27{,}000\ m^2$, a berth length of $465\ m$, a depth of $-10\ m$ ZH, and a storage capacity of 600 small vehicles. But the terminal does not present a ramp in its infrastructure, neither passengers' handling facilities, becoming unsuitable to the operation.

Lisbon's port has a multipurpose terminal in *Santa Apolónia*, that is mostly used by ships that operate connections lines between Lisbon and the RAM and RAA (*Região Autônoma dos Açores*). The terminal has a depth of $-6\ m$ ZH, a berth length of $480\ m$ and $48{,}200\ m^2$.

The multipurpose terminal, as the Ro-Ro terminal, does not present a ramp (fixed or floating) or passengers' handling facilities, not fitting in the necessities of the operation studied once the study is aiming the minimum investment necessary to operate the line.

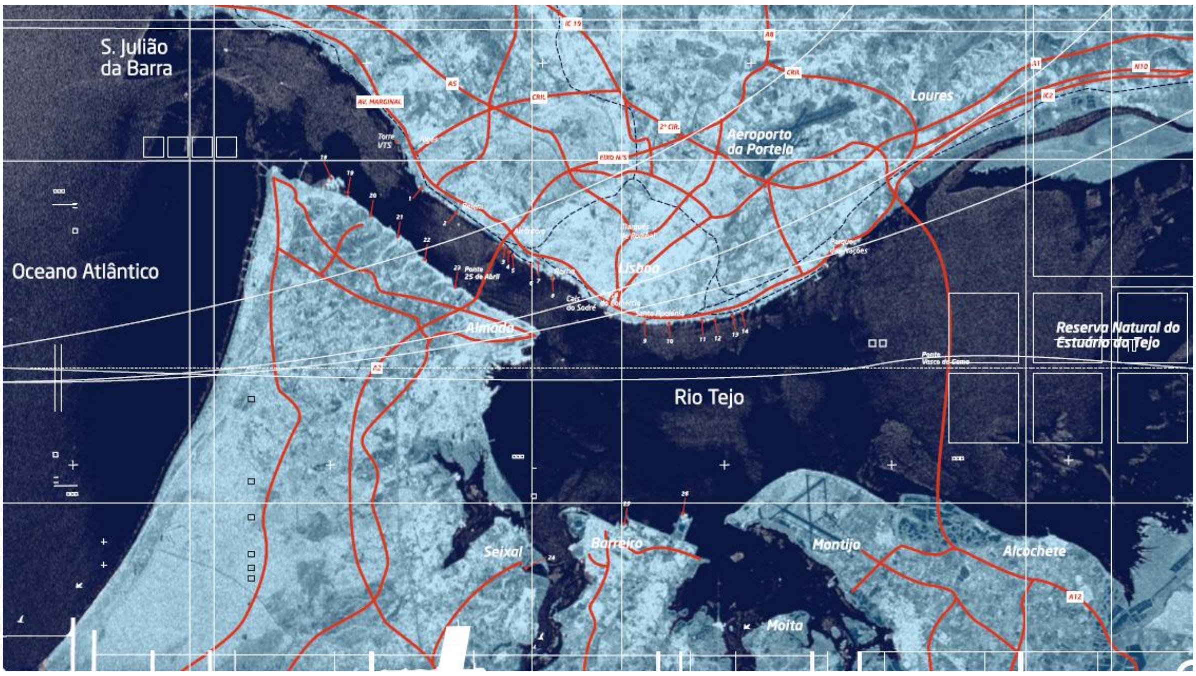


Figure 5 - Port of Lisbon, with railroad access [5]

[5] Source: APL, S.A. – *Administração Porto de Lisboa,S.A.*

The port also has two cruise terminals, one in *Santa Apolónia*, that offers passengers' buildings, with cruise facilities, namely check-in, panoramic deck, bars, and public parking. It also offers a quay of $1{,}490\ m$ in length but does not have a Roll-on/Roll-off ramp.

In the *Gares Marítimas da Rocha Conde de Óbidos* and of *Alcântara* there are another two cruise facilities smaller than the terminal, that operates in support it, with a quay of $483\ m$ and a depth of $-8.8\ m$ ZH in *Óbidos* and another quay of $465\ m$ and $-10\ m$ ZH in Alcântara.

Another feature of Lisbon's port is the large distance to the RAM, of approximately $530\ nm$ to the port of Funchal, adding to the operational cost of the trip.

- **Port of Setúbal (*Porto de Setúbal*)**

The port of Setúbal is located at 38º 30' N, 8º 55' W, in the estuary of the Sado River (*Rio Sado)*, having marine access and sheltered waters for ships, with also, modern port structure and equipment. The port has road access to the Portuguese national road network that surrounds the outline of the Setúbal city.

Figure 6 - Port of Setúbal with its roads accesses [6]

The port is composed of several specialized terminals, some can be pointed out as possible to the operation, they are the multipurpose terminals zone 1 and zone 2 (consented to TERSADO and SADOPORT, respectively), and the Roll-On/Roll-Off Terminal (consented to AutoEuropa). They have the following specification, as shown in Table 1.

[6] Source: APSS, S.A. – *Administração dos Potros de Setúbal e Sesimbra, S.A.*

Table 1 – Setubal port terminal's characteristics [7]

	Multipurpose Z1 (TERSADO)	Multipurpose Z2 (SADOPORT)	Ro-Ro (AutoEuropa)
Berth length	$864\ m$	$725\ m$	$365\ m$
Depth	-9.5 ZH + -10.5 ZH	$-12\ m$ ZH	$-12\ m$ ZH
Storage capacity	$102{,}000\ m^2 + 2{,}116\ m^2$	$200{,}728\ m^2 + 1{,}619\ m^2$	$150{,}000\ m^2$
RO-RO ramp installed	Yes ($30\ m$ width)	No	Yes

From these terminals, only the multipurpose zone 1 and the Ro-Ro terminals have a ramp, converging with the doss of the study of not having infrastructure investments in the ports, in the other hand none of these terminals possess the superstructure to receive passengers, even being almost $530\ nm$ of distance from Funchal.

- **Port of Portimão (*Porto de Portimão)***

The port of Portimão is located at 37º 07' N, 8º 31' W, in the estuary of the Arade River (*Rio Arade*), sheltered by two-wave breakers in the entrance of the port. Composed mainly of a cruise terminal, which means it has all the infrastructures necessary to operate with passengers, namely check-in, lobbies, bar/terrace, and ground support linking the port with the city center of Portimão.

The terminal offers a $330\ m$ quay, supporting vessels up to $215\ m$ in LOA and a maximum draft of $8.5\ m$.

[7] Source: Author's elaboration, based on APSS, S.A. website

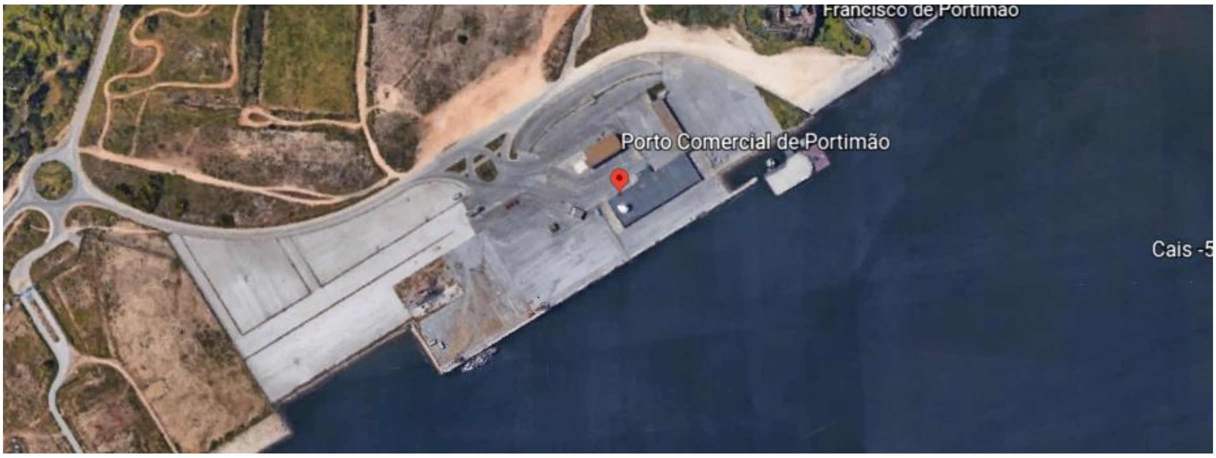


Figure 7 - Cruise Terminal Port of Portimão [8]

Taking into consideration the vessel description required by the Portuguese government, shown in, this port is suitable for the operation having the infrastructures to receive passengers and being almost $500\ nm$ away from Funchal, representing a fuel cost saving compared to the rest of the ports possible in the route.

The berth does not present Lo/Lo equipment, so all the cargo transported in the route must be rolling, being carried by translifters, full trucks, or trailers.

- **Port of Funchal (Porto de Funchal)**

The port of Funchal is located at 32° 38' N 16° 54' W, at the capital of the RAM - Funchal city, an artificial port, with great marine access, and access to the main road of the island (*via rápida 1* - VR1) that gives access to the counties of the main island of the archipelago.

[8] Source: Google Earth

Figure 8 - Port of Funchal [9]

The port is composed of several berths, most for fishing vessels and cruises. *Cais 1*, located in the far west point of the quay is equipped with a Ro-Ro ramp that is mostly used for the inter-island route Funchal- Porto Santos, usually operated by a medium-sized Ro-Pax ferry.

Figure 9 - Ro-Ro ramp in Funchal's port [10]

The berth has $150\ m$ in length, with a $32\ m$ width ramp, a depth of $-6.5\ m$ ZH, but does not present a Lo/Lo equipment, so all the cargo transported in the route has to be rolling.

Another important operational aspect of the port is the limited space in the terminal, obliging the trailers to be always accompanied by the respective tractor head. There is also no space in the port for parking trailers or containers, nor means/equipment for the movement of cargo. More than this, the operations will be subject to the availability, because of the sharing space with other port users, namely cruise vessels and the inter-island ferry.

[9] Source: Google earth
[10] Source: Google earth

2.2 Ship's and route characteristics

In this sense, taking into consideration all the ports described before and their physical characteristics, especially their distance to the RAM, the final route defined is the Portimão – Funchal, as illustrated in Figure 10, the same route operated between 2008 and 2011 and again in 2018.

Another important feature of the project is the ship's characteristics, which will be limited by the natural peculiarity of both selected ports for the route. Added to this, the route's characteristics themselves and governmental restrictions further restrict the ship's characteristics. This section will explain how the ship's main dimensions and properties are limited, and some governmental requirements important for the development of the methodology.

Figure 10 - Route between Portimão and Funchal [11]

Being this route a key connection between the Portuguese mainland and one of the most relevant insular regions of the country, it became an essential matter for the government to incentivate the different types of links between these two regions. Subsidization of the maritime line is already, in general, marked out by Decree-Law no. 134/2015 of July 24, which also regulates the terms of the mobility allowance air transport that has been applied since September 1, 2015.

As a public service of transportation, the Portuguese state makes a list of demands for minimum and maximum dimensions and proprieties of the vessels that will operate in the specified route. As designated in Autonomous Region of Madeira Regional Government (2018) the following restrictions are detailed, such as:

- The maximum LOA is $175\ m$;

[11] Source: ENM Ferries, adapted by the Author

- Maximum draft is $6.5\ m$;
- Minimum gross tonnage is $12{,}000$;
- Minimum service velocity is $18\ knots$;
- Minimum number of seats is 400 passengers and the minimum number of seats in cabins is 200 passengers;
- Minimum space capacity to transport $100\ small\ vehicles$;

Additionally, the document also describes some features of the trip. It is established that the minimum annual number of trips is $24\ voyages$, in the document the trip is called "*Viagens de Serviço Público"*, described as the trips that comply with the number of trips established in the Public Service Obligations. Each trip corresponds to the route, one way or back, between the island of Madeira and the Portuguese mainland.

From these minimum number of voyages, 24 trips must be done on a weekly frequency, between the dates June 1^{st} and September 15^{th} each year. All voyages must be done in accordance with a schedule predefined and must be done with a minimum commercial velocity of $21\ knots$.

The Portuguese government also predefines the maximum tariffs that can be charged for each different type of ticket. All the values are presented below in Figure 11, where it is possible to notice that the government defines different tariffs for all possible tickets. Providing specific tariffs for residents, students, and non-residents users in different categories of tickets, for low and high season. Important to notice that the government does not state maximum tariffs for the haulage of trucks. All information presented is only applicable if the vessels operating the route have all the different types of tickets shown in the image, not having one or multiple, this tariff is not applicable.

		TARIFAS MAXIMAS POR CADA TITULO					
Segmento de Tarifa :		Residentes		Estudantes		Não Residentes	
Época:		Alta	Baixa	Alta	Baixa	Alta	Baixa
TIPOS DE TÍTULOS	**Passageiros em cadeira:**	29,10 €	24,20 €	25,50 €	20,40 €	85,00 €	68,00 €
	Passageiros em camarotes:						
	Individual interior	79,80 €	63,80 €	69,80 €	55,90 €	199,50 €	159,60 €
	Duplo interior	59,85 €	47,85 €	52,35 €	41,90 €	149,65 €	119,70 €
	Quadruplo interior	39,90 €	31,90 €	34,90 €	27,90 €	99,80 €	79,80 €
	Individual exterior	99,70 €	79,80 €	87,30 €	69,80 €	249,30 €	199,40 €
	Duplo exterior	74,80 €	59,85 €	65,50 €	52,35 €	187,05 €	149,60 €
	Quadruplo exterior	49,90 €	39,90 €	43,70 €	34,90 €	124,80 €	99,80 €
	Suite (2 pessoas)	129,80 €	103,80 €	113,50 €	90,80 €	324,40 €	259,50 €
	Suite (1 pessoa)	259,50 €	207,60 €	227,00 €	181,60 €	648,70 €	519,00 €
	Crianças:						
	Até 3 anos:	Grátis		Grátis		Grátis	
	4 a 11 anos:	50% desconto		50% desconto		50% desconto	
	Veículos Ligeiros[1]:						
	Ligeiros:	125,00 €	115,00 €	125,00 €	115,00 €	125,00 €	115,00 €
	Motos:	40,00 €	35,00 €	40,00 €	35,00 €	40,00 €	35,00 €
	Bicicletas:	10,00 €	5,00 €	10,00 €	5,00 €	10,00 €	5,00 €
	Veículos elétricos:	50% desconto		50% desconto		50% desconto	

1 - Quando o passageiro viaje acompanhado do Veículo Ligeiro e adquira o Título relativo a Passageiro+Veículo Ligeiro em conjunto.

Figure 11 - Maximum tariffs by type of ticket [12]

2.3 Government positions on the route

The regional government provides incentives to the return of the route with some financial aids, especially in the first years of operation. Two main inducements are carried out, first for the residences users of the RAM, covering part of the tickets for those. The subsidy applied to the residents' tickets can be explained as:

- Voyage tickets without accommodation: 50% of the total price of the ticket
- Voyage tickets with accommodation: 40% of the total price of the ticket
- Voyage without accommodation + vehicle: 40% of the total price of the ticket
- Voyage with accommodation + vehicle: 30% of the total price of the ticket

All discounts are calculated over the total price charged by a passenger, having a limit of € $400,00$ for two-way tickets, or € 200.00 for one-way. When the total bill per passenger is over these limits the difference must be paid by the user. At the end of the year, the total difference is compensated by the

[12] Source: *Concurso Público Internacional para Concessão de Serviços Públicos de Transporte Marítimo de Passageiros e Veículos através de navio ferry entre a Madeira e o Continente Português, Anexo I, Cláusula IV, Estrutura Tarifária*

government directly to the service operator. The original text explaining the discounts is presented in Figure 48 - Governmental subsidy for residences in APPENDIX 3 – Original document.

Since the project takes the ship's operator perspective in the financial analysis, all the subsidies applied in tickets prices are not relevant, because it only changes the origin of the income revenue, not affecting the annual cash flow of the operation, since the government pays back the difference in those tickets values for the service provider.

Another big incentive made, is to apply an extraordinary reduction in the port tariffs in the first years of operation. The Executive Member of the Board of the APS, S.A. reports that the following progressive reductions will be made for the usage of the port, pilotage, mooring, and the passengers' haulage tariffs in the port of Portimão:

- 1st year of operation: reduction of 87.5% over the tariffs included.
- 2nd year of operation: reduction of 75% over the tariffs included.
- 3rd year of operation: reduction of 50% over the tariffs included.
- 4th and following years of operation: reduction of 18% over the tariffs included (until the 10th year of operation).

Likewise, the regional administration in Funchal's port also incentivates the service using tariffs reduction during the first years of operation. As stated in SRETC – APRAM (2016), the reductions are also applied directly in the port's services tariffs, namely, usage of the port, haulage of cargo and passengers, pilotage, and mooring. It can be explained as:

- 1st year of operation: free of tariffs.
- 2nd year of operation: reduction of 85% over the tariffs included.
- 3rd year of operation: reduction of 70% over the tariffs included.
- 4th and following years of operation: reduction of 50% over the tariffs included.

In addition to the above reductions SRETC – APRAM (2016) also declared that the promotion of the service in the Portuguese market will be sponsored with a financial volume of $€\,80\,000,00$, trying to engage the public. More than this, all Madeira goods will have 100% of the cost of haulage financed, if the good is produced in the RAM, as well as raw materials reprocessed there.

All port tariff reductions are applied in the tool directly in the voyage costs, namely port costs, affecting the total cash flow of the simulation.

2.4 Traffic and seasonality

According to the governmental requirements above mentioned, the year is divided into two periods:

- **High season:** from April to September and from December 15^{th} to January 15^{th}.
- **Low season:** rest of the days of the year.

This division can be explained because of the great difference between the demands of passengers during these two different periods of the years. This split opens the possibility of two different operation scenarios, with two different Freight Rates for the classes transported by the ferry. This seasonality can be easily illustrated by plotting the total number of passengers that passed in the port of Funchal during four years of operation (2008-2011), as shown in Figure 12. It is evident a greater demand for the service between July and September, most likely because of the residents returning to the archipelago with a cheaper way of transportation for the vacations, and travelers with caravans and trailers, very common among the visiting tourists of the RAM for the summer.

For the demand calculation purposes in the project, the months of January and December were considered as high season periods.

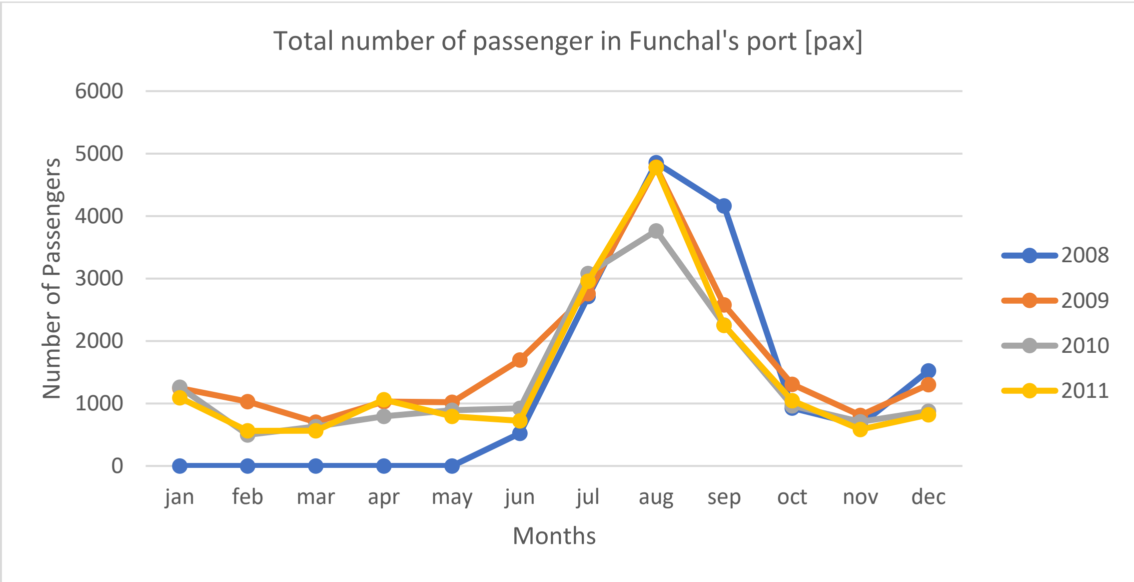


Figure 12 - Total number of passenger in/out Funchal's port[13]

The seasonality of the route is already known by the players and possible players consulted to operate the route in the past public tenders, according to with SRETC – APRAM (2016), the company Fast Reliable Seaways (FRS), from Germany, one of the shipowners interested in the operation in the last contract consultancy, claims that the volume of passengers is not sufficient to sustain the line, with strong seasonality, with good occupations only for 3 to 4 months per year. The same was alleged by other companies, such as Matrix, Marine Group (Cyprus).

Even though there is a strong seasonality in the route, during the first years of operation, the global quantity of passengers in the line is considerable. According to Funchal's port authority, the number of passengers between the years of 2009 and 2011 exceeded 20,000 passengers per year, reaching 23,730 passengers in 2009, as shown in Figure 13. Notice that in 2012 the route was only operated for

[13] Source: Author's elaboration, based on the APRAM reports

3 months, the reason why the total passengers are lower compared to the others. This Graph shows that there is a request for the service in the region, and this fact is confirmed by Quintal (2013) research survey, based on over 300 answers, showing that 75 % of the island population would use a ferry service to access the mainland.

Being this seasonality an important variable for the design of the Ro-Pax ship that will operate in the route, the project will stipulate the separated demands for each month of the year, taking into consideration historic seasonality data of passengers, better explained later in this report.

More than this, it is also known that the cargo transported in the route has greater significance southbound than northbound, reinforced by the total tonnage in and out of Funchal's port, meaning that the RAM imports more than export products from/for the mainland. This phenomenon is illustrated in Figure 14. Because of this great divergence in the imports and exports tonnage and knowing that the total number of TEU carried in both ways is almost the same, if not, the region would be overfilled, urges a need in the numerical tool to operate different FR for each way of the trip for trucks, and analyze the demands separately for each way of the trip.

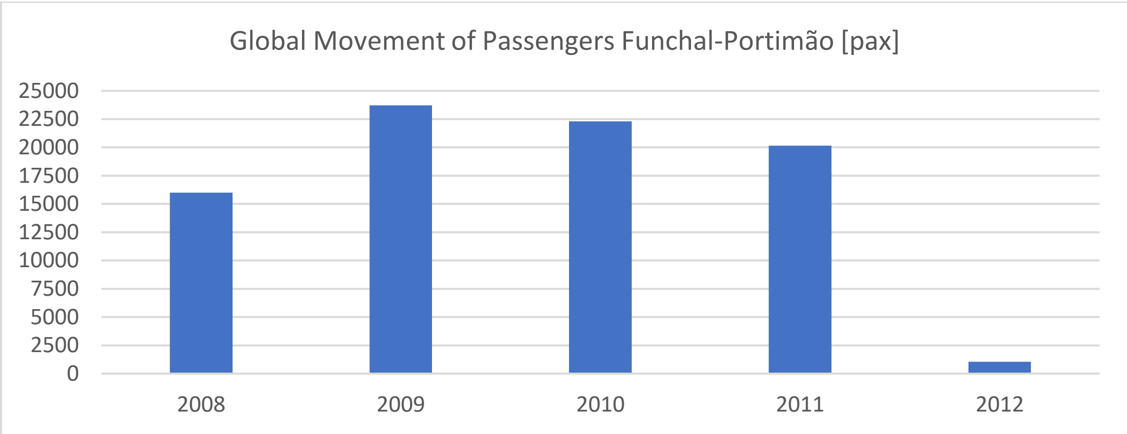


Figure 13 - Global movement of Passengers Funchal – Portimão [14]

Taking into consideration the different demand scenarios that the ship will have to operate, the first step to simulate the revenue of service is to estimate the demand in different seasons. The project uses the freight rate and the speed as variants to obtain the possible demand behavior of each class of goods carried (being passengers, cars, and trucks). Besides that, the project also uses non-resident passengers, non-residents cars, and truck prices as bases for the rest of the tickets.

[14] Source: Author's elaboration, based on the APRAM reports

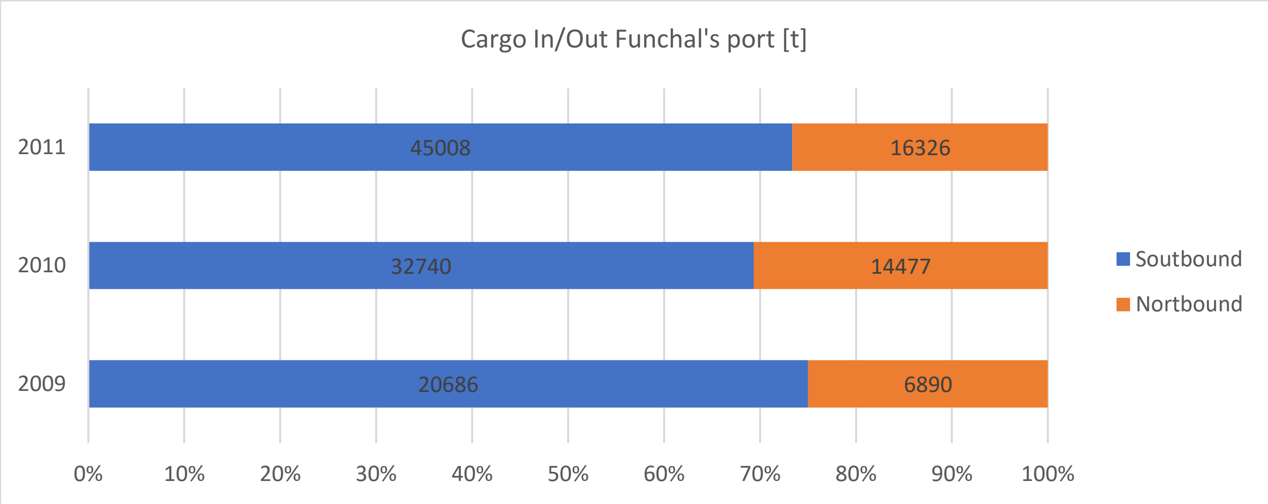


Figure 14 – Cargo in/out Funchal's port in tonnage [15]

Using the statics above a mathematical tool in Excel, which, as a first step, is given by the user: freight rates for each type of class and service speed, having as output, the monthly demand stipulated and the monthly revenue, as well.

In short, the method uses real statistics historic for a given know freight rate and service speed, to estimate the possible behavior of each class demand. Being this essentially an economic problem, related to the concept of elasticities of demand and knowing that the economic problem is not the main goal of the project, several reasonable assumptions are made to try to estimate the qualitative behaviors of each base class demand.

To begin, taking into consideration several differences of demand between southbound and northbound trips and high season and low season demands, several demand matrices are created, using as variables: ship's speed and freight rate FR. Precisely, six for each base class (one northbound and one southbound for each class: passenger, car, and trucks), having the numerical tool a total of twelve matrices to work with (high season and low season). Each matrix is created using a pivot point of demand (consequently, pivots speed and FR), from this point, taking into consideration the profile of the class, assumptions are made to fill the rest of the matrix of demand with percentages of the pivot.

For all the matrices the pivot speed is considered the same, $20\ knots$, calculated using the schedule of the past operation and the distance of the trip. For each pivot, FR is considered the value of the operated price of each ticket in the past operation. Finally, for the pivot demand, it is considered the average of the months of the season of the leg of the trip (north or south) considered, calculated using the average of previous operations (2008-2011).

Beginning with the passengers' behavior it is considered that the demand drops hugely if the speed is lower than the pivot and has a small increase if the opposite occurs, relating the preferences for trips in

[15] Source: Author's elaboration, based on the APRAM statistics

a shorter time. Now, with the variation of the FR, the demand varies linearly with a gentle slope for more or less than the pivot, decreasing for higher prices. An example of the monthly demand mapping is illustrated in Figure 15, the value of $1179\ passengers$ is used as pivot for the elasticity assumptions aforementioned, the result is shown in Table 2. The same method is used to estimate the demand of passengers northbound in high season, and both for the low season.

Table 2 - Monthly demand of passengers southbound in high season[16]

		Freigth Rate [€]							
		60	**70**	**80**	**90**	**100**	**110**	**120**	**130**
Speed [knot]	**18**	707	590	472	354	236	118	0	0
	19	1061	943	825	707	590	472	354	236
	20	1415	1297	**1179**	1061	943	825	707	590
	21	1474	1356	1238	1120	1002	884	766	648
	22	1533	1415	1297	1179	1061	943	825	707
	23	1592	1474	1356	1238	1120	1002	884	766
	24	1651	1533	1415	1297	1179	1061	943	825
	25	1710	1592	1474	1356	1238	1120	1002	884

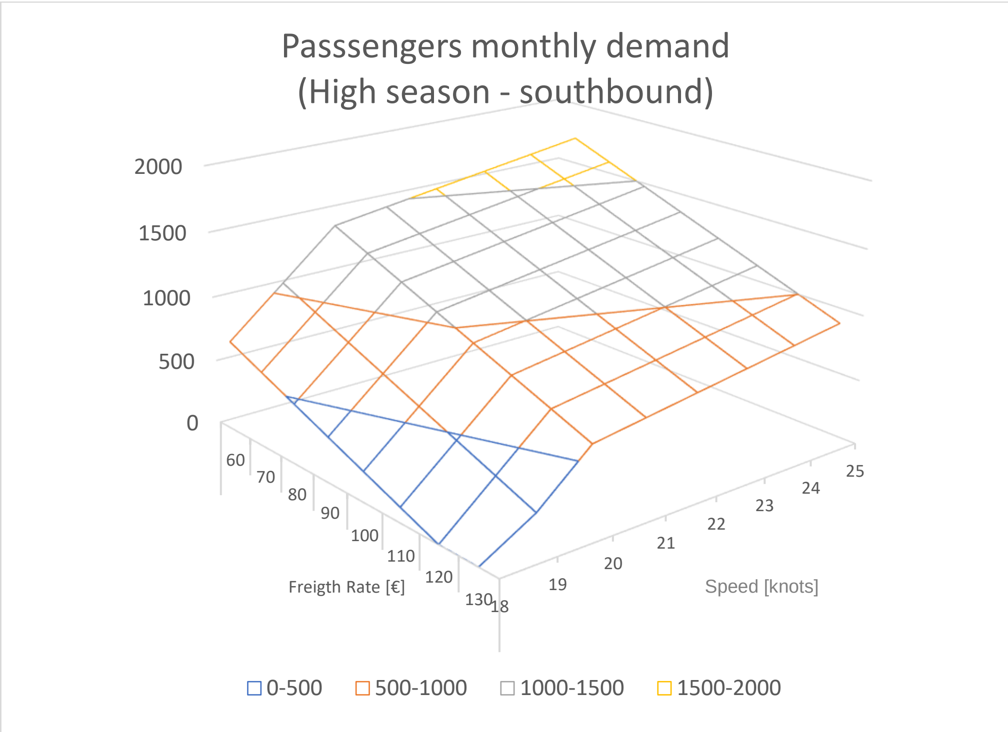


Figure 15 - Monthly demand of passengers southbound in high season[17]

[16] Source: Author’s elaboration

[17] Source: Author’s elaboration

For the cars' matrices, it was used the same method used for the passengers' demand matrix, assuming that the cars respect all presuppositions of the passengers since the passengers are the owners of the cars transported in the ferry, once all vehicles have to be accompanied by rule.

For the cargo demand, the analysis must be studied further, because of the lack of details in the data provided by the port of Funchal reports (APRAM (2013-2018)), it becomes a challenge to know the total number of trucks shipped. In those reports, are only provided the yearly carried cargo in and out of the port (in tonnage), with no detailing in the monthly movements. So, to obtain the variation of the demand each month it is assumed that the cargo of the ferry respects the same behavior of the containerized cargo transported from Lisbon to the RAM, namely the port of Caniçal. Aiming to identify this seasonality, the monthly transportation data from 2008 until 2019 was pulled up.

Figure 16 shows the total number of TEU shipped from Lisbon to Caniçal, between the years of 2017-2019. As is possible to analyze from the image, the containerized cargo demand does not present the same seasonality phenomenon, dissimilarly to the other goods carried. The behavior identified, expressed by the trendline in the graph, is used in the methodology created to represent the trucks in the route.

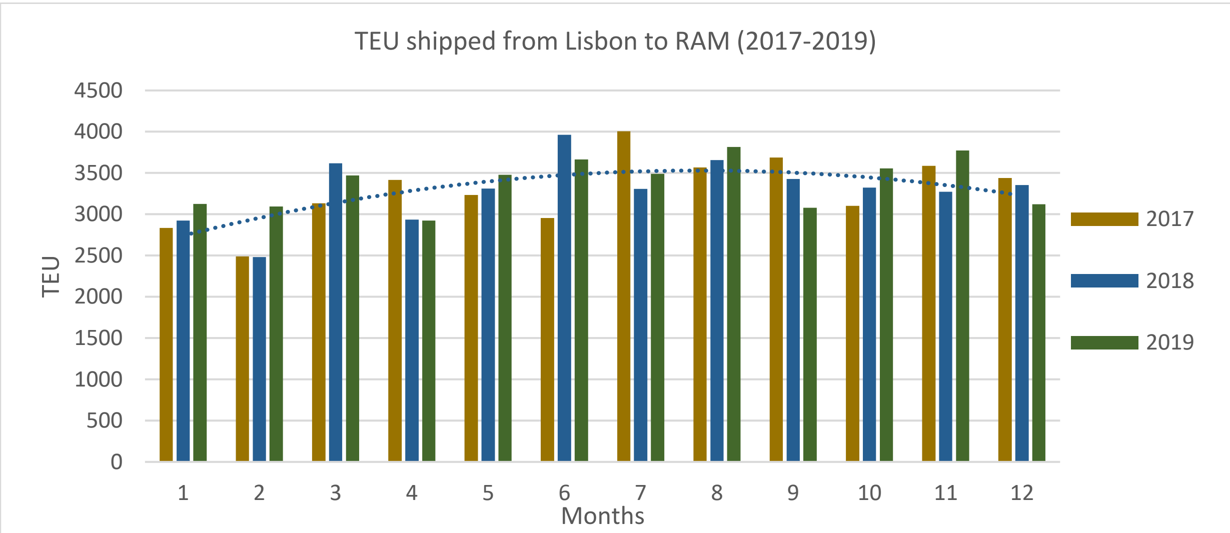


Figure 16 - TEU shipped from Lisbon to RAM (2017-2019) [18]

Now another problem appears, looking at the total number of TEU imported and exported from Lisbon, the total annual amount is almost the same, but the total tonnage exported is almost 5 times bigger than the imported, as shown in the 2019 data, illustrated in Figure 17. This can be explained by the supply of products that are not produced in the region, but at the same time, not flooding the region with empty containers, and the same occurring with trucks, so all of them must be returned to the mainland.

[18] Source: Author's elaboration, based on the APL statistics

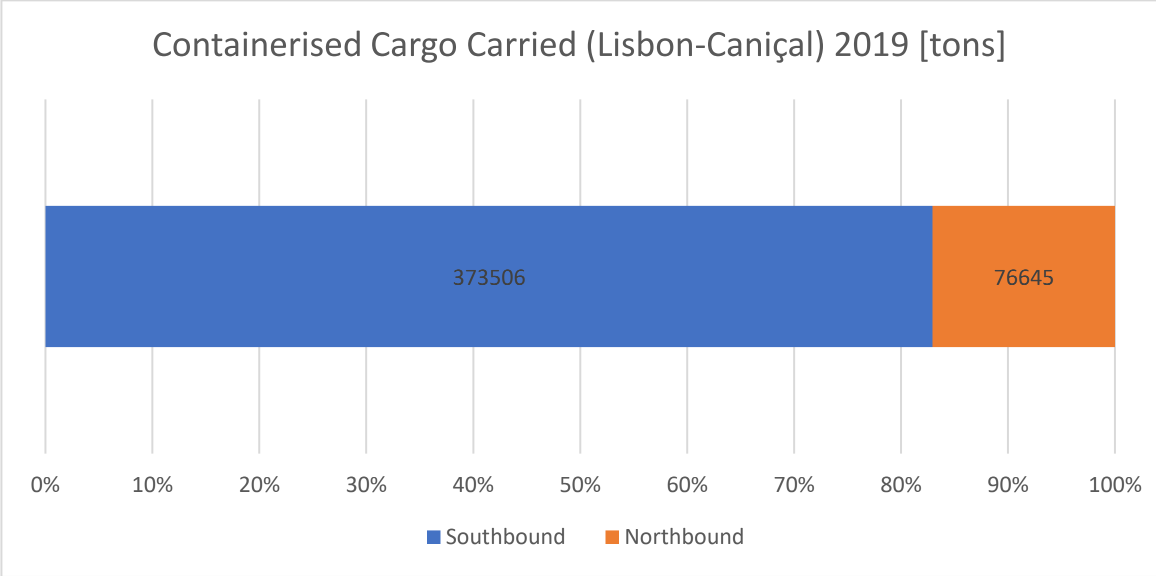


Figure 17 – 2019's Imports/Exports of the RAM to Lisbon[19]

To solve the problem, it was calculated the occupancy ratio of the cargo on each commercial leg of Lisbon-Caniçal, using the tares provided by the port of Lisbon data. Having an average occupancy of 85.8% southbound and 21.2% northbound, these ratios are applied to the average values of imports and exports of the cargo of the Funchal's port to obtain the total cargo, as if those were 100% of occupancy and then divided by $18\ tons/FEU$, because a trailer has almost the same size/weight of a forty-feet unit and for calculations purposes, can be considered as such.

Now, knowing the average number of trucks imported and exported by the ferry in the route and the monthly variation calculated previously (while studying the seasonality of the route), those are applied to obtain the estimation of the cargo transported each month of the year. Then, the average of each season is calculated and used as the pivot of the matrices of truck demand. However, the range of the FR in these matrices is different, so the numerical tool can have more elasticity.

For the cargo demand matrix, the demand response is linear to the variation of the FR and the Speed, taking into consideration that the behavior of this market is more constant than the passengers one. An example of the mapping of the demand is presented in Table 3 and illustrated in Figure 18.

[19] Source: Author's elaboration, based on the APL statistics

Table 3 - Monthly demand of trucks northbound in low season[20]

		Freigth Rate [€]											
		20	**120**	**220**	**320**	**420**	**520**	**620**	**720**	**820**	**920**	**1020**	**1120**
Speed [knot]	**18**	354,9	327,6	286,65	245,7	218,4	191,1	163,8	136,5	81,9	40,95	13,65	0
	19	382,2	354,9	313,95	273	245,7	218,4	191,1	163,8	109,2	68,25	27,3	0
	20	409,5	382,2	341,25	300,3	**273**	245,7	218,4	191,1	136,5	95,55	40,95	0
	21	423,15	395,85	354,9	313,95	286,65	259,35	232,05	204,75	150,15	109,2	54,6	0
	22	436,8	409,5	368,55	327,6	300,3	273	245,7	218,4	163,8	122,85	68,25	0
	23	450,45	423,15	382,2	341,25	313,95	286,65	259,35	232,05	177,45	136,5	81,9	0
	24	464,1	436,8	395,85	354,9	327,6	300,3	273	245,7	191,1	150,15	95,55	0
	25	477,75	450,45	409,5	368,55	341,25	313,95	286,65	259,35	204,75	163,8	109,2	0

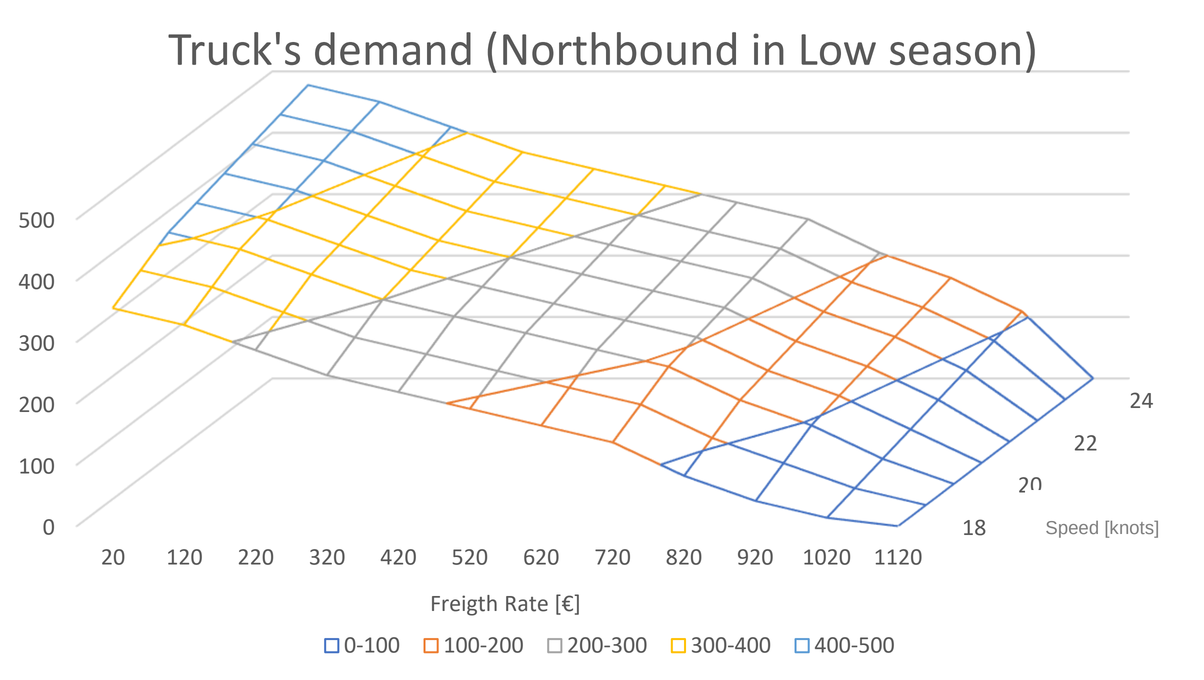


Figure 18 - Monthly demand for trucks northbound in Low season[21]

Once estimated all the demands, the methodology uses the service speed provided by the user to select the row of the matrices and maps between each column the FR provided is, then interpolating the values, the expected season demand is obtained. Respecting the seasonality, already traced, the yearly demand for each class is presented to the user.

Before calculating the revenue, the average ticket price for the passenger must be calculated, taking into consideration that there are different ways for the passenger to travel in long trips of Ro-Pax ships, being seated, in a two-person cabin, or a four-person cabin, etc. According to the previous service report (SRETC – APRAM (2016)), 50% of the population are in seats, and the rest in cabins, but not provided by type so, it is considered half in two-person cabins and the other half in four-person cabins. The prices are three and two times higher than the seated ticket price, respectively. Once the other classes do not present different types of tickets, the defined FR is used as the price of the tickets.

[20] Source: Author's elaboration
[21] Source: Author's elaboration

Having the demand for each class estimated all year round and the ticket prices specified, the annual revenue can be calculated. An important aspect must be pointed out, it is possible that a few stipulated demands can overburden the ship's maximum carrying capacity if this happens, the numerical tool corrects the revenue, fitting it within the ship's limits. Both situations are presented to the user as explained later in Chapter 3.4 Implementation in a numerical tool.

2.5 Literature Review

Before beginning with the methodology, it is necessary to review the works already done related to the theme of the thesis, firstly the analysis is done about the route chosen. Beginning with Quintal (2013), the first work done to study the feasibility of the route studied. Quintal analyses the feasibility of the creation of a complex route between the mainland and the autonomic regions of Portugal, RAM, and RAA.

It is done an overall analysis of both market for the creation of the ferry route, he identifies the seasonality of the route, pointing out the fact that both regions import more than export goods for the mainland. In the study all Portuguese ports are compared using their distances from each other and the tariffs for their operation, concluding that the most profitable route would be between *Setúbal*, *Ponta Delgada*, and *Caniçal.*

The first problem appears when the work does not consider the governmental requirements for the creation of the route between RAM and mainland, not respecting the possible ports for the operation. Moreover, the work also considers that the ship is always operating in its full capacity, and as seen before, that is impossible because of the behavior and seasonality of the market.

After defining the route and the timetable of the service, he identifies the fixed and variable costs for the operation. Taking average values for the fuel consumption and assuming always the same quantity of cargo to be handled (containers, Ro-Ro, and passengers), the cost structure is poorly characterized, specialty regarding the specification of the operating costs of the route.

Following the report, the author defines the freight rate of the cargo to have the breakeven of the operation, and later defines different margins of profit, claiming that the operation is profitable in all its legs. In the end, the author presents a public-opinion poll regarding the link between the regions, presenting the acceptance of the population about the creation of the service, trying to support the feasibility analysis done.

Added to Quintal, Freitas (2015) carries out a case study of the operation of the route by the *Naviera Armas*, trying to defend that the service must be considered as a public service, presenting the socio-economic impacts after the first termination of the operation in 2008 for the Madeira region, alleging that it was a pure business strategy to declare it as unsustainable.

The author takes a purely economic point of view in his analysis of the service, identifying the external economic forces that enclose the operation (*Porter Forces* [22]), pointing out the strategy of the company. Freitas identifies the critical factors for the success of the previous operation, among them, the lack of infrastructures in the Funchal port to optimize the Ro-Ro operations, high port tariffs in the RAM ports, and others.

The work also presents a legal analysis of the previous operator, *Naviera Armas*, its strategic goals when operating the line, and also presents strategic indicators and actions that the operator would be supposed to follow for the success of the service.

Once again, the study assumes some premises different from the present thesis, such as specific port equipment (tractors and Lo-Lo equipment) for the cargo handling, that opens the opportunity for the vessel to transport different cargoes, such as semi-trailers and containerized cargo. These assumptions avoid the necessity of truck head to be onboard and give the vessel more haulage capacity, not being trustful when computing the revenue or the time in port.

Both references are important to understand the political and some technical characteristics of the service, but being both economic studies, both present different visions of the operational impact and lacking methodological analysis in the field of marine traffic, the conclusions reached may be grounded in some wrong assumptions and must be investigated further. Being this the idea of this thesis, to analyze the technical feasibility of the route.

Both investigations identify the importance of the governmental roll in the maintenance of the service, as also pointed out by other authors for different European routes, such as Baird (2007), Styhre (2009), Douet and Cappuccilli (2011), Baindur and Viegas (2011) Aperte and Baird (2013), Ng, Sauri, and Turró (2013), and Suárez-Alemán (2016), in different feasibility works.

Furthermore, Santos and Soares (2016) presented a model to evaluate the feasibility of a Ro-Ro service, modeling its demands by considering the amount of cargo carried between the regions linked. The authors analyze the amount of potential cargo that can be carried, applying decision-making criteria to a suitable transport solution between both regions, sizing the required fleet to supply it.

The model created in this work is similar to the one used in the project to identify the potential market of the service. Using as variables the FR and the ship's speed, the model produces the potential cargo to be carried for each situation studied. The model also uses statistical data to support the calculations of the numerical tool created. But the article considers both transit time and costs for unimodal (road) and intermodal transportation solutions.

To test the model, the authors use the methodology to characterize the demand for cargo transportation between Leixões-Rotterdam using a Ro-Ro ship. Using the statistical data for marine and road haulage,

[22] Concept presented by autor in Porter, Michael. (1986). Estratégia competitiva: Técnicas para a análise de indústrias e da concorrência. 7ª ed. Rio de Janeiro: Campus, 1986.

the authors analyze the total time and final FR for the transportation of the FEU or trailer, between both regions, using different unimodal and intermodal solutions.

They conclude that for pure Ro-Ro transportation is there is no need for high speeds because increasing sailing speeds above 14–15 knots do not lead to substantial gains in cargo volumes. On the contrary, decreasing FRs leads consistently to an increase in SSS transportation demand.

Having a more general approach in the SSS theme for a Ro-Pax ship, Tsamboulas et al. (2015) present a study on this type of ship employed in Adriatic routes carrying freight between NUTS 3 regions. Short sea shipping, in the past years, has been well studied for routes within, or just connecting Mediterranean ports, and this study comes in the line of other studies, such as that of Sambracos and Maniati (2012) and Tzannatos et al. (2014), which considered SSS routes using Ro-Pax ships between ports in Greece. More than those, Suárez-Alemán et al. (2015) and Lupi et al. (2017). Baños et al. (2016) made interesting studies on the economic impact of an Atlantic Ocean SSS route in tourism in northern Spain.

Another work presented that also uses the same methodology to represent the demand of the route as a function of the FR and the service speed is exposed by Santos and Soares (2017). The work defines the main characteristics of a cargo Ro-Ro ship and the required fleet size to supply the route's demand. The model also calculates time charter, voyage costs, and revenue considering the main particulars calculated.

The model only uses database parameters for sizing the required ship characteristics, after that, uses well-known formulae to structure the costs related to the operation, using as variables the fuel costs, time charter costs, emission control area, installed propulsion power, and stacking factor. They also apply in the model route restrictions added to service restriction, such as maximum voyage time and minimum load and unload time for the service.

The authors test the model in the Leixões-Rotterdam route, identifying the most suitable ship fleet for different market penetration factors (different scenarios are tested), quantifying the impact on shipping company profit with changes in the parameters above mentioned, and stipulating the optimal ship and fleet size, for a yearlong operation.

Dundara, et al. (2010) presented a report of an innovative Ro-Pax vessel designing process. The primary focus was on the general ship design (Naval Architecture calculations: speed, power, damage stability, etc.) performed previously. Different propulsion variants were compared and evaluated during the study. The authors try to optimize some structural parameters, to obtain a lower Equipment Number and smaller Gross Tonnage reducing additionally vessel's price and port fees. Various structural arrangements of the midship section and superstructure were analyzed as a multi-objective design problem. An approach that combined ship general and ship structural design have been suggested for the early design stage, maximizing the key performance factors of the project.

Finally, regarding sizing and predesign process studies, Papadopoulos (2019) presented a diploma thesis in which the author uses a parametric procedure for sizing this type of vessel, implemented for the preliminary design of large Ro-Pax ferries. Having all parameters calculated, the author combines the developed model with design space exploration and optimization algorithms to design a techno-economically optimal ship.

This review of literature allows the conclusion that there are relatively few studies linking SSS transportation demand under different maritime freight rates and ship speeds and the sizing of a ship to supply it. For this purpose, it is necessary to support the calculations with database analysis and particulars formulae created, to connect the different freight flows forecasted from modal with the sizing process of the vessel to operate the desirable route.

3. METHODOLOGY

Being one of the most used types of vessels for the operation of short sea shipping, Ro-Pax ships have a great advantage compared to the normal specific cargo/passenger vessels, that is the possibility of carrying both types simultaneously. In the past years, this “new” type of ship is winning more and more space in the global market, especially in Europe and Asia and, this fact can be corroborated by Figure 19, which shows that the average number of passengers in a Ro-Pax vessel increased more than two times in the past forty years.

As the Ro-Pax ships are built for a large variety of purposes, it becomes almost impossible to create a unique methodology to design this kind of vessel. Therefore, this project has two objectives in this process of pre-dimensioning the required ship for the route:

- To create a database based on the “Significant Ships” published yearly by RINA for several years, with different types of Ro-Ro and Ro-Pax vessels. Creating analytics formulae for basic design purposes of the project.
- Use already published formulae created using different databases for Ro-Ro and Ro-Pax ferries from other projects.

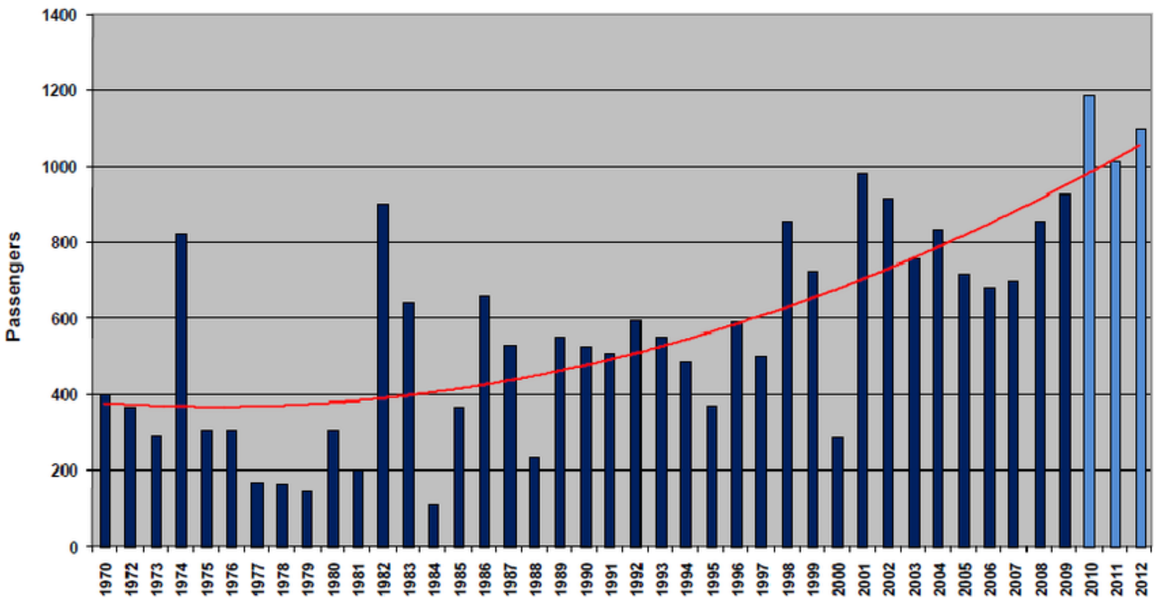


Figure 19 - Average number of passengers on Ro-Pax vessels[23]

The first step in any database evaluation is to define in which direction the analysis must head. In the case of roll-on/roll-off ships, there are two main types: Ro-Ro ships, carrying up to 12 passengers; Ro-Pax ships, carrying more than 12 passengers. In our case, only vessels included in the second category

[23] Source: ShipPax, NAVITASHIP

will be considered. According to Kristensen and Psaraftis (2016), this second group of Ro-Pax can be also subdivided into two other subgroups:

- Ships with low cargo capacity: ships with less than $1.5\ lanemeter/passenger$ and less than $6\ ton\ of\ DWT/passenger$
- Ships with high cargo capacity: ships with more than $1.5\ lanemeter/passenger$ and more than $6\ ton\ of\ DWT/passenger$

According to the author, the majority of high cargo capacity ships have their capacity below $1{,}000$ passengers reaching $1{,}500$ passengers, being this the case of study of this project. On the other hand, the first subgroup has its capacity ranging up to $3{,}200$ passengers.

3.1 Sizing method for Ro-Pax Ships

Ro-Ro vessels were officially defined in November of 1995 amendments to Chapter II-1 of the SOLAS (Safety of Life at Sea), 1974 as being “a passenger ship with ro-ro cargo spaces or special category spaces”, they were initially built in the 19th century to transport trains too heavy for bridges across rivers. Among the various types of Ro-Ro vessels, Ro-Pax is the one built for freight vehicle transport with passenger accommodation, for more than 12 passengers.

3.1.1 Main dimensions and main coefficients

According to Wijnolst and Wergeland (2009), the best approach for designing a Ro-Ro vessel to supply a certain demand is to use the lanemeters capacity as the main parameter of the design process. Therefore, the first important step is to define this variable of the required ship.

In the numerical tool, this capacity is defined by the user as a percentage of the maximum demand of trucks added to another percentage of the maximum demand of the cars/pax, in a specific way or both ways of the trip, all year round. Having both demands added, the value is transformed into the required lanemeters, by multiplying the number of trucks by 16.50 meter per truck, and 5.5 meters per car.

After the required lanemeter capacity is defined, the overall length is calculated using a formula created based on the Ro-Pax database created in the project, partially available in APPENDIX 1 – RO-RO ship database.

$$L_{OA} = 31.461 \times Lmt^{0.2251} \quad [m] \tag{1}$$

Where Lmt is the lanemeter capacity calculated.

Then, using the calculated length overall, the length between perpendiculars, the breadth, the draught, the height of the weather deck (uppermost continuous deck above the keel), the maximum draught can be calculated using the following formulae, based on the analysis of technical data of Ro-Ro ships (Kristensen and Psaraftis, 2016):

$$Lpp = 0.922 \times LOA - 0.95 \quad [m] \tag{2}$$

$$B = 0.083 \times Lpp + 11.64 \quad [m] \tag{3}$$

$$T = 0.0191 \times Lpp + 3.01 \quad [m] \tag{4}$$

$$D = 0.05 \times Lpp + 6.94 \quad [m] \tag{5}$$

$$T_{max} = 0.55 - 0.0015 \times Lpp + T \quad [m] \tag{6}$$

With the main dimensions calculated, the user defines the following parameters: the block coefficient (Cb), the sea margin for the calculations of resistance, type of propeller arrangement (single screw, twin screw, or twin-skeg), number of blades, type of propulsion plant (2xDiesel 4 strokes or 4xDiesel 4 strokes), if the hull has appendages (stabilizer fins) and the capacity of the fuel tank.

After the user defines all the design parameters, using the technical analysis available in the literature and created analysis, are calculated some secondary parameters for the ship, such as deadweight of cargo and passengers, gross tonnage, midship section area coefficient, waterplane area coefficient, propeller diameter, wetted surface, length in the water plane, the volume of the hull and displacement. All of those parameters are calculated using expressions created based on studies from different ship database analyzed on different papers.

According to Kristensen and Psaraftis (2016), these secondary parameters can be calculated using the following formulae for high cargo density vessels:

$$\frac{DWT_{cargo}}{Lmt} = 138 \times Lmt^{-0.494} \tag{7}$$

$$\frac{DWT_{pax}}{pax} = 849 \times pax^{-0.689} \tag{8}$$

$$\frac{GT}{\Delta} = 0.0000156 \times \Delta + 1.16 \tag{9}$$

$$C_{midship} = \begin{cases} 0.975\,, & if\ C_b > 0.68 \\ 0.38 - 1.25 \times C_b^2 + 1.75 \times C_b, & if\ C_b \leq 0.68 \end{cases} \tag{10}$$

$$C_{wl} = 0.7 \times C_b + 0.38 \tag{11}$$

Where:

DWT_{cargo} *and* DWT_{pax} – is the deadweight of cargo and passengers, respectively,

Lmt – is the lanemeters capacity of the ship,

pax – is the maximum passenger capacity of the ship,

GT – is the gross tonnage of the ship,

Δ - is the displacement of the ship,

$C_{midship}$ - is the midship section area coefficient,

C_b – is the block coefficient,

C_{wl} – is the waterplane area coefficient,

Now, to calculate the propeller diameter, wetted surface, and length in the water plane is necessary more attention, because the analysis of these parameters depends on the type of propeller defined by the user. The equations for the calculations change by the type of propeller chosen: single screw, twin screw, or twin-skeg. The equations are presented below:

$$L_{wl} = \begin{cases} 1.01 \times Lpp\,, & if\ is\ Single\ Screw \\ 1.035 \times Lpp\,, & if\ is\ Twin\ Screw \\ 1.04 \times Lpp\,, & if\ is\ Twin - Skeg \end{cases} \quad [m] \tag{12}$$

$$D_{prop} = \begin{cases} 0.56 \times T_{max} + 1.07\,, & if\ is\ Single\ Screw \\ 0.71 \times T_{max} - 0.26\,, & if\ is\ Twin\ Screw \\ 0.85 \times T_{max} - 0.69\,, & if\ is\ Twin - Skeg \end{cases} \quad [m] \tag{13}$$

For the calculations of the wetted surface of the ship, is usually used Mumford’s formula, but according to Kristensen and Psaraftis (2016), the results obtained during his project using this formula range up to 15% of the difference to the real value of the Ro-Ro ships analyzed. So, the paper proposes a modification for the original formula trying to adapt it to this specific type of ship. Not being enough, the modified formula still needed a correction considering the block coefficient of the ship, enhancing the accuracy of the formula.

The original Mumford’s formula is as follows:

$$S_w = 1.025 \times Lpp \times (C_b \times B + 1.7 \times T) = 1.025 \times \left(\frac{\nabla}{T} + 1.7 \times Lpp \times T\right) \quad [m^2] \tag{14}$$

The final formula used in this project to calculate the wetted surface is:

$$S_w = \begin{cases} 0.87 \times \left(\frac{\nabla}{T} + 2.7 \times L_{wl} \times T\right) \times (1.2 - 0.34 \times C_{bw}), & if\ is\ Single\ Screw \\ 1.21 \times \left(\frac{\nabla}{T} + 1.3 \times L_{wl} \times T\right) \times (1.2 - 0.34 \times C_{bw})\,, & if\ is\ Twin\ Screw \\ 1.13 \times \left(\frac{\nabla}{T} + 1.7 \times L_{wl} \times T\right) \times (1.2 - 0.31 \times C_{bw})\,, & if\ is\ Twin - Skeg \end{cases} \tag{15}$$

According to the paper, the average difference in percentage between the results obtained with the different versions of Mumford's formula is considerable, as illustrated in Table 4.

Table 4 - Difference in % between the results of Mumford's formula variations [24]

Ship Type	Original Mumford's formula	Modified Mumford's formula	Modified Mumford formula with block coefficient correction
Single Screw	4.94	1.86	1.34
Twin Screw	5.80	2.80	2.53
Twin-skeg	10.68	2.15	1.65

Besides these calculations, is also presented in the paper some analysis for non-dimensional design coefficients for high cargo density Ro-Pax ships. The tool uses this data to check if the values previously calculated are within the average limits for this type of vessel. The non-dimensional coefficients calculated are Lpp/B, B/T, Lpp/T, L/D, and $\frac{Lpp}{\nabla^{1/3}}$.

Having the block coefficient and the midship section area coefficient, the prismatic coefficient can be calculated, following the following formula.

$$C_p = \frac{C_b}{C_{midship}} \tag{16}$$

3.1.2 Hull parameters

To estimate the length of the engine room, are used two methods and the average values between both are considered. The first method uses the database created in this project, with two regressions created, one for two main engines set and another for four engines set, both using the propulsive power as a variable, presented below. The second uses a formula predefined in the literature, also presented by Ventura (2016).

From the database of Ro-Ro ships created:

$$L_{ER} = \begin{cases} 7.097 \times HP^{0.0938}, & if\ 2\ motors\ set \\ 4.9359 \times HP^{0.1405}, & if\ 4\ motors\ set \end{cases} \tag{17}$$

From the literature:

$$L_{ER} = 0.002 \times HP + 5.5 \qquad [m] \tag{18}$$

[24] Source: Kristensen H. O and Psaraftis, H. (2016): Analysis of technical data of Ro-Ro ships. Report. The Technical University of Denmark

Where HP is the propulsive power installed.

Then, the volume of the engine room can be calculated using:

$$V_{ER} = L_{ER} \times B \times T \times C_b \times 0.85 \quad [m^3] \tag{19}$$

3.1.3 Basic Hydrostatics and Stability

With some of the hull's parameters defined, basic hydrostatics and stability calculations are done, namely, the center of buoyancy ordinate (KB), the buoyancy center abscissa (LCB), and the transverse metacentric radius (BMT).

The buoyancy center ordinate (KB), given in meters, is calculated with different formulas from different sources, namely, Normand's formulae, Schneekluth formula, Wobig formula, and Vlasov formula, according to Ventura (2016), and the highest value calculated is used for the calculations. There are the following:

$$KB = T\left(\frac{5}{6} - \frac{1}{3} \times \frac{C_b}{C_{wl}}\right), \qquad Normand \tag{20}$$

$$KB = T\left(0.9 - 0.36 \times C_{midship}\right), \qquad Normand \tag{21}$$

$$KB = T\left(0.9 - 0.3 \times C_{midship} - 0.1 \times C_b\right), \qquad Schneekluth \tag{22}$$

$$KB = T\left(0.78 - 0.285 \times \frac{C_b}{C_{wl}}\right), \qquad Wobig \tag{23}$$

$$KB = \left(0.372 - 0.168 \times \frac{C_{wl}}{C_b}\right) \times T, \qquad Vlasov \tag{24}$$

For the buoyancy center abscissa is given as a percentage of the L_{pp} measured from the midship section, being positive values for the bow direction is used Schneekluth and Bertram (1998) formula, shown below:

$$LCB = \frac{8.80 - 38.9 \times F_n}{100} \qquad [m] \tag{25}$$

Where F_n is the Froude number of the ship, given by:

$$F_n = \frac{V}{\sqrt{g \times L_{wl}}} \tag{26}$$

Being g the gravity, V the ship's velocity in m/s and L_{wl} the ship's length in the waterplane.

Then, the transverse metacentric radius is calculated (BMT) using different approaches and, again, the maximum value is taken to be used in the design process of the vessel. The transverse metacentric radius is defined by:

$$BMT = \frac{I_{xx}}{\nabla} \qquad [m] \tag{27}$$

Where the I_{xx} is the transverse moment of inertia of the water plane, and it can be approximated using $I_{xx} = k_r \times B^3 \times L$, in which the k_r is a coefficient that is obtained from Table 5.

Table 5 - Coefficient Kr for the approximation of the transverse moment of inertia [25]

C_{WL}	K_r	C_{WL}	K_r	C_{WL}	K_r
0.68	0.0411	0.78	0.0529	0.88	0.0662
0.70	0.0433	0.80	0.0555	0.90	0.0690
0.72	0.0456	0.82	0.0580	0.92	0.0718
0.74	0.0480	0.84	0.0607	0.94	0.7460
0.76	0.0504	0.86	0.0634	0.96	0.7740

It can be also defined by:

$$BMT = \frac{f(C_{wl}) \times L \times B^3}{12 \times L \times B \times T \times C_b} = \frac{f(C_{wl})}{12} \times \frac{B^2}{T \times C_b} \qquad [m] \tag{28}$$

Where $F(C_{wl})$ is the reduction factor, and different authors have delineated different equations to define it, including Murray, Normand, Bauer, N.N. and Dubszus and Danckwardt, according to Ventura (2016). All the formulae are shown below, and for the calculation of the BMT the highest value calculated between these formulae is used:

$$f(C_{wl}) = 1.5 \times C_{wl} - 0.5\,, \qquad Murray \tag{29}$$

$$f(C_{wl}) = 0.096 + 0.89 \times C_{wl}^2\,, \qquad Normand \tag{30}$$

$$f(C_{wl}) = 0.0372 \times (2 \times C_{wl} + 1)^3\,, \qquad Bauer \tag{31}$$

$$f(C_{wl}) = 1.04 \times C_{wl}^2\,, \qquad N.N. \tag{32}$$

$$f(C_{wl}) = 0.13 \times C_{wl} + 0.87 \times C_{wl}^2 \pm 0.005\,, \qquad \text{Dubszus and Danckwardt} \tag{33}$$

[25] Source: Estimation Methods for Naval Architecture, Prof. M Ventura (2016)

For the stability parameters, the first one is the metacentric height (KM), defined by:

$$KM = B(13.61 - 45.4 \times \frac{C_b}{C_{wl}} + 52.17 \times \left(\frac{C_b}{C_{wl}}\right)^2 - 19.88 \times \left(\frac{C_b}{C_{wl}}\right)^3 \qquad [m] \tag{34}$$

But for vessels with $0.73 < \left(\frac{C_b}{C_{wl}}\right) < 0.95$, according to Schneekluth and Bertram (1998), this equation can be replaced by:

$$KM = B(\frac{0.08}{\sqrt{C_{midship}}} \times \frac{B}{T} + \frac{0.9 - 0.3 \times C_{midship} - 0.1 \times C - b}{\frac{B}{T}} \qquad [m] \tag{35}$$

After that, approximating the tabular freeboard with a parabolic curve regression of the values from the Load Lines Convention is possible is to obtain the following expression for the ships Type B, defined by the same convention:

$$FB = -0.016944 \times L_{fb}^2 + 22.803499 \times L_{fb} - 691.269920 \qquad [m] \tag{37}$$

L_{fb} is defined as the freeboard length according to the IMO definition, expressed in the project as:

$$L_{fb} = 0.95 \times L_{pp} \qquad [m] \tag{38}$$

3.1.4 Propulsive power and resistance

To estimate the propulsive power required by the vessel it is necessary to estimate the total resistance of the hull, for that, the method of Holtrop and Mennen (1982) will be used.

The method is based on statistical regression of the model tests and results from ship trials, using a systematic series of the experimental data. This systematic series is a family of hulls obtained from variations of one or more shape parameters. The resistance of all the models that constitute a series is measured experimentally. In this way, it allows the interpolation of the resistance coefficient for other shapes originated by the parametric variations of the original shape.

Being a well-known method to estimate the resistance of vessels in the preliminary stages of ship designing, this report will not cover the mathematical aspects of the method, just shown the assumptions used for the calculations of the propulsive power required.

Table 6 shows the explanations of each variable of the previously mathematical expression. It must be observed, the value of R_{TR} will be assumed as zero, this is because is assumed that the transom is above the waterline (not submerged).

In this way, the total resistance can be written as:

$$R_T = R_F(1 + K_1) + R_{APP} + R_w + R_B + R_{TR} + R_A \qquad [kN] \tag{39}$$

Table 6 – Resistances [26]

R_F	*Friction resistance*	*[kN]*
$(1+K_1)$	*form factor of the hull*	-
R_{APP}	*Appendage resistance*	*[kN]*
R_w	*Wave making resistance*	*[kN]*
R_B	*Bulb resistance*	*[kN]*
R_{TR}	*Transom resistance*	*[kN]*
R_A	*Additional resistance from model/ship correlation*	*[kN]*
R_T	*Total Resistance of the ship*	*[kN]*

Explaining each one of those, begging with the friction resistance. It is possible to calculate its value using the equation (40) below:

$$R_F = \frac{1}{2} \times \rho \times c_f \times S_w \times v^2 \qquad [kN] \tag{40}$$

Where:

R_F -is the friction resistance,

ρ – is the seawater density, with the value of $\rho = 1.025$ [ton/m^3],

v - is the ship's velocity given in [m/s],

c_f – is the friction coefficient, given by:

$$c_f = \frac{0.075}{(\log R_n - 2)^2} \tag{41}$$

Being R_n Reynold's number given by:

$$R_n = 1000 \times \frac{\rho \times v \times L_{OA}}{\mu_{sw}} \qquad [kN] \tag{42}$$

μ_{sw} – is the dynamic viscosity of the saltwater

The $(1+k)$ is the form factor, is composed of $(1+k_1)$ that is the form factor of the naked hull and $(1+k_2)$ that is the form factor of the appendages, following the equation (43) below:

$$(1+k) = (1+k_1) + [(1+k_2) - (1+k_1)] \times S_{app}/S_w \tag{43}$$

Where S_{app} is the wetted surface of the appendage, and the value of $(1+k_2)$ is predefined and is shown below in Table 7.

Table 7 - Values for the appendage's form factor [27]

[26] Source: Estimation Methods for Naval Architecture, Prof. M Ventura (2016), adapted
[27] Source: Estimation Methods for Naval Architecture, Prof. M Ventura (2016)

Configuration of the Hull Appendages	$1+k_2$
Rudder (1 propeller)	1,1~1,5
Rudder (2 propellers)	2,2
Rudder + structs (1 propeller)	2,7
Rudder + boss (2 propellers)	2,4
Stabilizer Fins	2,8
Bilge Keels	1,4
Domes	2,7

The wave-making resistance R_w represents the waves generated and broken waves by the hull. It is expressed by:

$$R_w = c_1 \times c_2 \times \exp[m_1 F_n^{-0.9} + m_2 \cos(\lambda F_n^{-2})] \times \Delta \times g \qquad [kN] \tag{44}$$

Below is illustrated the equations for each of the coefficients unknown in the equation (44) above, being α the semi-angle of entrance of the load waterline, expressed in degrees.

$$\lambda = 1.446 C_p - 0.03 L/B \tag{45}$$

$$c_1 = 2223105 \left(\frac{B}{L}\right)^{3.78613} \left(\frac{T}{B}\right)^{1.07961} (90 - 0.5\alpha)^{-1.37565} \tag{46}$$

$$c_2 = \exp\left(-1.89\sqrt{c_3}\right) \tag{47}$$

$$m_1 = 0.0140407 \frac{L}{T} - 1.75254 \frac{\nabla^{\frac{1}{3}}}{L} - 4.79323 \frac{B}{L} - 8.07981\, C_p + 13.8679 C_p^2 - 6.984388 C_p^3 \tag{48}$$

$$m_2 = -1.69385\, C_p^2 \exp\left(-\frac{0.1}{F_n^2}\right) \tag{49}$$

$$c_3 = \frac{0.56 A_{BT}^{1.5}}{BT(0.56\sqrt{A_{BT}} + T_F - h_B - 0.25\sqrt{A_{BT}}} \tag{50}$$

The semi-angle can be obtained using:

$$0.5\alpha = 125.67 \times \frac{B}{L} - 162.25 \times C_p^3 + 0.155087 \times LCB^3 \quad [^o] \tag{51}$$

The bulb resistance is computed from the expression:

$$R_B = \frac{0.11 \times \exp(-3 \times p_B^{-2}) \times F_{ni}^3 \times A_{BT}^{1.5} \times \rho \times g}{1 + F_{ni}^2} \qquad [kN] \tag{52}$$

Where the variables are obtained from:

$$F_{ni} = \frac{V}{\sqrt{g \times i + 0.15 \times V^2}} \quad [kN] \tag{53}$$

Being A_{BT} is the area of the appendage and V is the volume of the vessel. The other variables are defined as:

$$p_B = \frac{0.56\sqrt{A_{BT}}}{T - 1.5 \times h_B} \tag{54}$$

$$i = T - h_B - 0.25 \times \sqrt{A_{BT}} \tag{55}$$

Finally, the model-ship correlation is expressed by:

$$C_A = 0.06 \times (L_{OA} + 100)^{-0.16} - 0.00205 + 0.003 \times c_2 \times C_b^4 = \frac{R_A}{\frac{1}{2} \times \rho \times S_w \times v^2} \tag{56}$$

Summing all those values the numerical tool obtains the value of the total resistance of the vessel, and with this, it calculates the power required for the main engines.

To compute the required power, there are still some assumptions made, being those the efficiencies of the hull, of the gearbox and the shaft, also the relative rotation efficiency and the open water efficiency, listed below in Table 8

Table 8 - Propulsive Coefficients [28]

η_H	*Hull Efficiency*
η_G	*Gear Box Efficiency*
η_M	*Shaft Efficiency*
η_R	*Rotation Relative Efficiency*
η_O	*O.W. Efficiency*

Finally, the total power required for the ship is given by:

$$HP_{total} = \frac{R_T \times v}{\eta_h \times \eta_g \times \eta_s \times \eta_r \times \eta_o} \quad [kW] \tag{57}$$

But this value is not the maximum power of the machinery, because it is assumed that to provide this power the main engine will be operating at 90% of its full capacity, so the engine power is higher than the value found in the equation (57) above, giving the P_{MCR} value.

[28] Source: Adapted from Ventura (2016), Estimation Methods for Naval Architecture, Instituto Superior Técnico, Lisbon, Portugal

The electric power needed can be also estimated using the formula for Ro-Ro ships, according to Giernalczyk & al (2010):

$$P_{EL} = 2432 + 0.14944 \times P_{MCR} \quad [kW] \tag{58}$$

Besides those power, aside thruster can be also estimated for the ship, justifying the not usage of tug in the ports during the operation. For that, first, we can estimate the side thrust needed by the ship, given by:

$$F_{side} = f \times L_{pp} \times T \quad [kN] \tag{59}$$

Where $f = 0.10 \left[\frac{kN}{m^2}\right]$

Finally, the power required for the thruster is:

$$P_{side} = \frac{F_{side}}{c \times \eta_E} \quad [kW] \tag{60}$$

Being $c = 0.150\ [kN/kW]$ and $\eta_E = 0.95$, being those the conversion factor and the efficiency of the side thrust motor.

3.1.5 Weights

With all these calculations done, the next is to estimate the lightship weight. To do it is necessary to first define hull weight, machinery weight, propeller weight, the center of gravity ordinate. Beginning with the hull weight estimation using the following expression, according to Ventura (2016).

$$W_H = 0.0313 \times L_S^{1.675} \times B^{0.850} \times D^{0.280} \quad [t] \tag{61}$$

Subsequently, the machinery weight can be estimated, based on statistical analysis regression (d'Almeida, 2009):

$$W_M = 1.88 \times P_{MCR}^{0.60} \quad [t] \tag{62}$$

With this, another important weight for the total lightship weight is the propeller one, it depends on the number of blades of it, defined by the user in the numerical tool. The formula used is according to Gerr (2001):

$$W_{prop} = \begin{cases} 2.14 \times \left(\frac{D_{prop}}{0.3048}\right)^{3.05}, & if\ z_{prop} = 3\ blades \\ 3.23 \times \left(\frac{D_{prop}}{0.3048}\right)^{3.05}, & if\ z_{prop} = 4\ blades \end{cases} \quad [t] \tag{63}$$

Where D_{prop} is the diameter of the propeller and z_{prop} is the number of blades.

Regarding the equipment weights, a formula obtained from the statistical analysis regression of general cargo vessels is used, (d'Almeida, 2009). The weight of the equipment is defined by:

$$W_E = 0.5166 \times (L \times B \times D)^{0.75} \quad [t] \tag{64}$$

Important to observe that due to the lack of specific studies regarding statistical estimation for several aspects of the Ro-Pax ships, the numerical tool needs to work with general cargo formulas, probably leading to larger errors in the estimates. This fact can lead to errors and an overestimation of some aspects of the required ship. Especially regarding the new building prices estimation, that considers the weights to guess the working hour for the construction and reflects the contract price.

3.2 New building price of Ro-Pax Ship

For the newbuilding price estimation, the first step is to define the costs of steel equipment purchase and installation and machinery. For that, it is necessary also to calculate the labor working hours to build and assemble the vessel, including any extras costs that are normal in shipyards.

3.2.1 Hull building costs

The number of man-hours spent in manufacturing a vessel is highly dependent on the efficiency of the shipyard. For the hull, it can be roughly estimated by the following expression (Carreyette, 1977):

$$Mh_H = 227 \times \frac{W_H^{\frac{2}{3}} \times L_{pp}^{\frac{1}{3}}}{C_b} \quad [M.h] \tag{65}$$

Where W_H is the weight of the hull in tons.

The price of marine steel can vary a lot, especially depending on where the material is, the quality, if it is treated or not. The prices can vary from $\$ 400.00$ up to $\$ 1{,}000.00$ on the plate. In the project, a value of $\$ 605.00$ is considered for each ton of the material. Following the ENVC Set. (1999) the average price of the manhour labor is around $\$ 20.00$, and this value is also used in the numerical tool.

In this way, the production cost and the material costs of the hull become, respectively:

$$CP_H = Mh_H \times u_{Mh} \quad [US\$] \tag{66}$$

$$CM_H = W_H \times u_{steel} \quad [US\$] \tag{67}$$

Where the Mh_H is the manhour spent in the production and assembling of the hull structure, u_{Mh} is the unit cost of the manhour, and u_{steel} is the unit price of the ton of steel used in the production. And summing these values estimated is obtained the hull building cost.

3.2.2 Equipment costs

The equipment cost is mainly dependent on the time spent in the installation, and this depends on the size of the vessel. The hours spent in the installation can be stipulated using:

$$Hh_E = Z \times L \times B^{\frac{1}{2}} \quad [M.h] \tag{68}$$

Where Z is a coefficient that receives the value of 400, guessed as the value higher than mom-sophisticated vessel but lower than a high-tech one.

With the time spent, it is possible to calculate the cost of installation of the equipment, multiplying the time by the unit cost of the equipment, which can vary from $\$\,1{,}000.00/ton$ for outfitting up to $\$\,3{,}500.00/ton$ for deck machinery equipment, as these values can vary a lot, and in the project is not defined all the equipment necessary to the vessel, the average value is taken ad assumed for all the equipment. The equipment cost is calculated following:

$$CP_E = W_E^{0.95} \times u_E + Hh_E \times u_{Mh} \quad [US\$] \tag{69}$$

Another important feature in the equipment cost for the building of the vessel is the special equipment, for example, the side thrust, that can significantly change the total equipment cost. In this way, using the power required by the side thruster, the cost is calculated using:

$$CP_t = (175 + 1.4 \times P_{side}) \times 100 \quad [US\$] \tag{70}$$

After having both costs, it is possible to calculate the total equipment cost by summing both of the previous values.

3.2.3 Machinery costs

The machinery costs can be expressed by:

$$CP_M = 1.6 \times \left(\frac{P_{MCR}}{100}\right)^{0.82} \times u_M + CF_M \quad [US\$] \tag{71}$$

Where m_M is the unit cost of the machinery, for a medium speed diesel engine this value can be assumed as $m_M = \$\,7{,}200.00 \ [US\$/kW]$, and CF_M is the cost of installation and alignment of the engine, given by:

$$CF_M = Mh_M \times u_{Mh} \quad [US\$] \tag{72}$$

The number of man-hours spent in machinery installation and outfitting is given by:

$$Mh_M = 1600 \times \left(\frac{P_{MCR}}{100}\right)^{0.6} \quad [M.h] \tag{73}$$

With all costs for the building, assembling, and outfitting stipulated the total contract cost can be calculated. To do it is considered in the numerical tool the shipyard's profit of 10%, over the total cost. Besides that, in a ship construction contract is common to have additional costs along with the building of the vessel, and in the project these values are also considered in the final cost, representing an 8% additional cost for the final value of the newbuilding cost of the ship.

3.3 Costs structure for Ro-Pax ships

The annual cash flow considered for the calculations of costs of the operation can be divided into three main categories: Capital Costs, Operating Costs, and Voyage Costs.

Before explaining the structure and calculations for each category, is important to observe that the ship is only operating on specific days throughout the year. In this sense, the operating and capital costs must be proportional to the service period of the vessel, meaning for both costs the numerical tool calculates the total yearly amount, but only consider the operational period.

The total number of navigation days and port time during the year are added and the result is divided by the total number of days in the year. This ratio is a factor applied in both costs, which means, only charging when the ship is operating in this route. The methodology does not take into consideration the period when the ship is not operating in the route for any of the calculations. Additionally, the discount factor is only applied after done all the cash flow of the operation.

3.3.1 Capital Costs

Capital costs are the debts arising from the construction contract of the vessel. Here are included the capital invested in the construction of the ship in the shipyard, the additional costs of contract, bank loan installments, insurances of the building, bank guarantees of investments, and bank interests.

In the numerical tool, the user can define the discount rate, the percentage of the owner investment in building the vessel, the percentage of the guarantees of the investment, and the interest rate.

The methodology generates eight equal installments to pay the bank loan, added to guarantees, and the bank interests as components of the capital costs in the cash flow.

Important to notice that in the cash flow, the first year is considered as "year 0", is the year where the shipowner does his part of the investment, but in practice, this "year" is just a day and does not have any of the other components, namely operating and voyage costs, neither a revenue, because there is no operation of the ship.

In the Total cash flow of the 20 years of operation, the user can define a scrap value, if applicable, and the value is also included in this category, but not being a cost, it is considered as a return of part of the investment made in the ship at the end of the operation of the route.

On the other hand, in SSS services, is normal to have the chartering of a vessel to operate the route. In this sense, a theoretical annuity must be calculated to simulate this scenario. The first step is to calculate the CRF (Capital Recovery Factor) for the period of the operation, $20\ years$, and it follows equation (74):

$$CRF = \frac{\tau(1+\tau)^t}{(1+\tau)^t - 1} \tag{74}$$

Where:

τ – is the discount rate,

t – is the time of the operation,

Then, the theoretical annuity of the ship is calculated following equation (75). All the values are calculated bringing them to their present value for 20 years of operation and using 8 years of payback period. The installments for the bank allowance are calculated using the well-known German repayment system, which consists of a sequence of varying annual installments, which includes an interest component and an equal partial repayment (constant amortizations) in each one of them. This annual cost is spread in all the years of the operation, and it becomes the capital investment for the operation.

$$Annuity = (Initial\ Investment + Installments + Interest + Residual\ Value)\ \ [US\$/year] \tag{75}$$

More than this, when chartering a vessel, it is possible to find the ship only operating the specific route during some days of the month/week. Knowing this, it becomes necessary to distribute the annuity fee over the days of the month that the ship is operated the specific route, just considering the costs that are related to the operation.

3.3.2 Operating Costs

The operating costs are divided into six different types of costs:

- Manning Costs
- Store and Consumables Costs
- Maintenance and Repairs
- Insurance and P&I Costs
- Administration Costs
- Periodic Maintenance

The Manning costs are all the costs related to hiring and managing the crew for the ship. It is considered the number of crew members calculated previously during the design and sizing of the vessel. Regarding the employment policies applied for the crew, it is considered all the crew is composed of south European employees, being so, the average annual cost of the crew is assumed to be $41{,}000\ USD$. The formula used to guess the annual costs for manning is shown below:

$$\$\,Manning_{cost} = K \times N^{0.95} \quad [US\$/year] \tag{76}$$

Where:

$K -$ is the coefficient of cost, related to the type of vessel and type of crew members,

$N -$ is the number of crew members in the vessel,

Being a SSS regular line in Portugal, and being a Portuguese built vessel, it is assumed that the crew is composed in its total of Portuguese crew members registered in MAR (*Registo Internacional de Navios da Madeira*). That is why the coefficient K assumes the value of $41000\ USD$ in the equation (76) above.

The Store and Consumables are the costs that mainly depend on cabin store capacity, in other words, depends on the size of the crew. Added to this, it is also related to the lubricating oil purchase for the machinery room, this cost is related to the size of the vessel and the propulsive power installed and the engine technology installed. For this type of cost the equation used to estimate its annual value is shown below:

$$\$\,Store\ and\ Consumables_{costs} = K_1 \times N + K_2 \times CN^{0.25} + K_3 \times HP^{0.7} \quad [US\$/year] \tag{77}$$

Where N is the number of crew members onboard, CN is the cubic number of the vessel, calculated using $CN = Lpp \times B \times T$, and the HP is the propulsive power installed in the ship. The coefficients K_1, K_2 and K_3 are related to the type of vessel studied (it is a tank vessel or a dry cargo vessel) and type of propulsive plant installed (diesel motors two or four strokes, or steam turbines). The values used in the project are:

$K_1 = 3500$ - crew consumables,

$K_2 = 4000$ - regarding dry cargo vessels,

$K_3 = 250$ - regarding 4 strokes diesel motors,

Maintenance and Repairs costs are the ones related to all small or routine repairs in the vessel that does not require the stop of the operation to be done, namely, small works are done in the machinery room, pump rooms, boiler rooms, repairs in cabins and superstructure of the ship, among others. It is also included the cost of spare parts that the vessel needs to continue to operate if happens a breakdown of any machinery small equipment.

The equation used for the assumption of this cost uses the new building price and the propulsive power installed as variables is as follows:

$$\$Maintenance\ and\ Repairs_{costs} = K_1 \times \$P + K_2 \times HP^{0.66} \quad [US\$/year] \tag{78}$$

Where:

$\$P$ - is the new building price of the vessel,

HP – is the propulsive power installed,

K_1 and K_2 – costs coefficients, being K_2 related to the type of propulsive plant installed,

In the project, the coefficients above assume are the following values $K_1 = 0.0035$ and $K_2 = 125$ related to four-stroke motors in the machinery room.

The Insurance and P&I costs are the costs related to the insurance of the vessel/flee for physical damage or losses, that compound almost $2/3$ of these costs, and the rest is related to third party liabilities (damage to cargo, pollution damage, crew, and others). The hull cover is made by a marine insurance company and the third party is usually covered by P&I (Protection & Indemnity) club.

The equation used to simulate this cost follows:

$$\$Insurance\ and\ P\&I_{costs} = K_1 \times \$P + K_2 \times GT \quad [US\$/year] \tag{79}$$

Where $\$P$ is the ship value and GT is the Gross tonnage of the vessel. K_1 and K_2 are coefficients related to the ship's type and ship's DWT, in the project the values assumed are the ones related to dry cargo ships with DWT between $20000\ ton$ and $80000\ ton$, namely, $K_1 = 0.008$ and $K_2 = 5.00$.

For Administration Costs are the ones related to registration flag, shore base administrative, management costs, communication costs, and miscellaneous costs. It is assumed a fixed annual cost of $\$\ 70000\ USD$.

Finally, the Periodic Maintenance of the vessel is related to special surveys (classification societies request) and/or drydocking repairs to the structure or bottom of the ship, these are the repairs that require the complete stoppage of the operation to be performed. For the project, Tzannatos, & al (2014) claim that the average cost for periodic maintenance for Ro-Pax ships changes every 5 years, always related to the initial price of the ship. Table 9 shows the formulae used for the calculations of the periodic costs during the twenty years of operation of the vessel:

Table 9 - Periodic maintenance formulae used [29]

Periodic Maintenance	**Tzannatos & al, 2014**	
1-5 years	$\frac{0.75}{100} \times \$P$	$[USD/year]$
6-10 years	$\frac{1}{100} \times \$P$	$[USD/year]$
11-15 years	$\frac{1.5}{100} \times \$P$	$[USD/year]$
16-20 years	$\frac{2}{100} \times \$P$	$[USD/year]$
21-26 years	$\frac{2.5}{100} \times \$P$	$[USD/year]$

[29] Source: Author's elaboration

Where $\$P$ is the new building cost of the ship.

3.3.3 Voyage Costs

The voyage costs have two main components:

- Fuel costs
- Port costs

The first one is calculated using some predefined parameters added to user-defined variables. The first step to simulate the fuel consumption of the vessel is to define the load of the main engines and generator set during the navigation and in port, assumed to be the two main moments with the great difference between loads of the machinery. In real life, there can be more moments with different loads, namely maneuvering and anchoring, but for the project, these are not considered relevant for the global consumption of fuel of the vessel.

Is defined for the sailing a load of 90% for the main engine and 80% for the generators, considering that the ferry always has a great consumption of electrical energy, once the ship is full of passengers and because of that, there is all the hoteling consumption necessary for a passenger ship. On the other hand, in port, the loads predefined to the set are 5% and 85%, respectively, once the main machine is kept at the minimum, but the hotel load remains high because of the passenger's needs.

After defining the loads for each set, is calculated the total of fuel in tons consumed per voyage of the ship. For the consumption of the main engine, is used the data created in the database of Ro-Pax ships, two linear regressions are used with the propulsive power as a variable, one for four main engines set and another for two. The coefficients obtained for each case are $a = 0.0033$ and $b = 13.254$, and $a = 0.0048$ and $b = -12.266$, respectively.

Having the quantity of fuel consumed, the density of the fuel is corrected, and then, the daily tank volume is calculated with a 40% margin for safety. After this, the SFOC of the set is calculated and compared with the average SFOC of a diesel four-stroke engine.

The voyage consumption of fuel for the main engine is calculated using the following equation, is added a margin of safety considering the different sea conditions in the different trips:

$$F_{main/voyage} = SFOC_{main} \times P \times t \times \frac{\eta_{main}}{1000000} \times 1.03 \quad [L/trip] \tag{80}$$

Where:

$F_{main/voyage}$ - is the consumption of fuel for the main engine per voyage,

$SFOC_{main}$ – is the specific fuel oil consumption calculated for the main engine, using the database created,

P – is the propulsive power,

t – is the time of navigation,

η_{main} - is the load of the main engine,

Multiplying the voyage consumption by the total number of voyages in the year, it is possible to obtain the total consumption of fuel for the main engines during the year of operation. Having the price per ton of the fuel, defined by the user, it is calculated the total fuel cost for the main engine sailing.

The same idea is used to calculate the main engine fuel consumption in port, but with a different load, and the time in port is defined by the user also, considering that the ferry has a port time directly linked with the superstructure of the port, number of ramps (loading/unloading equipment) of the ship, and number of cargo (trucks, cars, and passengers) that must be shipped.

Likewise, the generator set consumption is calculated, but this time the consumption rate is obtained using an average consumption rate for Genset of $2500\,kW$, the value obtained in literature search, partially available in APPENDIX 2 – Generator set Specifications. It is used the total electric power estimated previously in kVA, using the power factor of 0.9, and multiplying by $24\,hours$, is obtained the theorical daily power consumed in the vessel if the generators were used during the whole day, but it is known that this does not represent the reality, so the quantity of fuel consumed will be calculated later, considering the time and the load in the generators. With this value in hand, the daily volume of the generator's fuel tank is calculated, then the density is corrected to calculate the quantity of diesel consumed daily by the ship. At the same time is also calculated the SFOC of the Genset, using the average consumption rate and the fuel density. The formula (80) is used for diesel consumption in port and sailing per voyage, multiplying by the number of trips, is obtained the year quantity of diesel consumed, and finally, the annual diesel fuel cost is calculated. Summing both fuel costs, it is obtained the annual total fuel costs of the route.

The voyage costs also include the costs of the port, these costs are related to port taxes, cargo taxes, pilotage, and mooring tariffs. Consulting the tariffs regulations of both ports, all the costs are calculated, as the following, for both regulations, the vessel is considered as a regular linear of a Ro-Ro ship, which results in some reductions in some costs.

For the APARAM (*Administração dos Portos da Região Autónoma da Madeira, S.A.*), namely the Funchal port, the first tax calculated is the use of the port (TUP) by the ship, it mainly depends on the GT of the vessel and the time in port. For this type of ship, the use of the berth is calculated using the following equation:

If the time in port is lower than $24\,hours$:

$$TUP_{funchal} = K_1 \times GT \qquad [€/operation] \tag{81}$$

Otherwise:

$$TUP_{funchal} = K_1 \times GT + \left(\frac{t_{port}}{24} - 1\right) \times K_2 \qquad [€/operation] \tag{82}$$

Where GT is the gross tonnage of the vessel, t_{port} is the time in port, and K_1 and K_2 are coefficients that depend on the ship type, in this case, they assume $K_1 = € \, 0.11$ and $K_2 = € \, 0.0474$. But as the ship is considered as a Ro-Ro vessel in a regular line for passenger transportation, it receives a reduction of 45%.

For the cargo, it is charged a tariff of € $50{,}00$ per passenger car without commercial commodities, € $75{,}00$ per empty truck, and € $140{,}00$ per full truck that passes in the terminal, no matter if loading or unloading at Madeira. Added to that, there is a tariff of € $0{,}50$ per passenger, a value that must be added with a tax of € 0.50 per passenger for baggage check equipment use.

In the port of Funchal, the pilotage service is mandatory and is calculated using the gross tonnage of the vessel. Regardless of whether is entering the port or leaving, the service is calculated by time of maneuver, in the project is considered that the ship only needs an hour to complete the maneuver (no extra taxes must be paid), being that said, the formula used to calculate the pilotage cost is:

$$Pilotage_{funchal} = Cn \times UP \times \sqrt{GT} \quad [€/operation] \tag{83}$$

Where:

Cn – specific coefficient depending on the type of ship,

UP – Pilotage unit value,

GT – Ship's gross tonnage,

The Cn coefficient for Ro-Ro ships performing maneuvers in/out the port is $Cn = 1.10$ and the pilotage unit value is fixed, and it is $UP = € \, 5.90$. The pilotage tax receives a reduction of 50%, for being a regular liner Ro-Ro vessel for transportation of passengers.

The last component of the port tariffs for the Funchal's port is the mooring taxes, it is charged the tax of € $226{,}00$ per indivisible period of an hour. In the project is considered that the mooring maneuver takes half an hour, but in each trip, the way is necessary to operate a mooring and an unmooring, having in total one hour of the service, need to pay the double of the unit value for each time the ship goes to Funchal.

Besides the tariffs in Funchal, is also calculated the tariffs in Port of Portimão, this time, the TUP is calculated as a conditional situation. The TUP tax follows the equation (89) below:

$$TUP_{portimao} = \begin{cases} U_1 \times GT \,, & if \; R \geq K \\ U_2 \times GT + U_3 \times QT, & if \; R < K \end{cases} \quad [€/operation] \tag{89}$$

Where:

U_1, U_2 and U_3 – unit tax, depending on the ship's type,

GT – is the ship's gross tonnage,

QT – is the total of cargo loaded/unloaded, expressed in tons,

R – is the relation calculated using $R = QT/GT$,

K - is the reference value of the relation,

For Ro-Ro vessels, the reference value of the ratio is $K = 0.96$. The unit taxes for this type of vessel are, respectively, $U_1 = € \, 0{,}4262$, $U_2 = € \, 0.1455$, and $U_3 = € \, 0.2911$. And the reduction applied to regular liners is 40% off from the total tax value calculated.

The pilotage services are charged following the equation (90):

$$T = Cn \times UP \times \sqrt{GT} \qquad [€/operation] \tag{90}$$

Where T is the pilotage costs, Cn is service coefficient, UP is the unit value of pilotage, and GT is the ship's gross tonnage. For entering and leaving the port, the Cn assumes the unit value. The pilotage unit value is $UP = \, € \, 7.9521$. In the project, this value must be paid twice, one going in the port and another leaving every time the ship goes to the mainland. Is also considered that each maneuver takes half an hour to be performed, meaning no extra taxes must be paid. It is applied to a reduction of 30% for ships operating in a regular line.

Table 10 - Mooring prices in Portimão's port [30]

(un: EURO)

Classe de GT		Serviço de amarrar	Serviço de desamarrar	Serviço de correr ao longo do cais
Classe	GT			
1	Até 999	137,1200	137,1200	137,1200
2	1.000 a 1.999	180,7476	180,7476	180,7476
3	2.000 a 4.999	266,7555	266,7555	266,7555
4	5.000 a 7.449	310,8613	310,8613	310,8613
5	7.500 a 9.999	337,3269	337,3269	337,3269
6	10.000 a 13.999	396,3910	396,3910	396,3910
7	14.000 a 19.999	426,3077	426,3077	426,3077
8	20.000 a 24.999	461,2348	461,2348	461,2348
9	≥ 25.000	498,6255	498,6255	498,6255

In this port, there are no taxes paid for rolling cargo, but there is a passenger tariff of € 3.3264 per passenger in or out of the ship.

Paying attention that all the values provided for port costs are given in euros and all the cash flow calculations are made in USD, so a currency transformation must be applied, this one must be provided to the numerical tool by the user.

3.4 Implementation in a numerical tool

In this section the numerical tool will be shown, demonstrating step by step the usage of it, what are the inputs and outputs for each part, and demonstrating the calculations layout developed for the results. Important to notice that the content of the calculations done has already been explained previously in this chapter.

The first step when using the numerical tool is the definition by the user of the freight rate, service speed, and the number of voyages to be carried out, allowing calculating its impact on the cargo and passengers demand for transportation, as illustrated in Figure 20 below.

[30] Source: Sines, Administração do Porto de, (2012), *Regulamento de Tarifas da APS, SA 2013*, Sines, Administração do Porto de Sines

User Control Panel

				Month	Monthly departures from Portimão
Service Speed [knots]	20			Jan	4
		25.0 hours/trip		Feb	4
Freight Rate [euros]	**High Season**	**Low Season**		Mar	4
Non-resident passenger	78	78	(65-135)	Apr	4
Non-resident car	100	100	(90-160)	May	4
FEU cargo southbound	1496	(850-2350)		Jun	4
FEU cargo northbound	420	(80-1180)		Jul	4
				Aug	4
				Sep	4
				Oct	4
				Nov	4
				Dec	4

User parameters are the ones in grey, you can change to test the program!
Attention, between june 1 and september 15, must be 24 trips!

SEE DEMAND | SEE REVENUE

Figure 20 – Operation parameter user's control panel [31]

As is possible to see in the figure above the user is leads to two options of results, the first one the demand related to the user's input. The demand is expressed in six different parameters, the passenger's, the car's, and the truck's demand, separately for north and southbound, as shown in Figure 21.

Southbound

	Monthly Demand [unit]		
	PAX	**CAR**	**TRUCKS**
Jan	387	338	183
Feb	340	129	182
Mar	280	145	217
Apr	604	237	197
May	546	324	207
Jun	715	353	214
Jul	1586	785	230
Aug	2726	857	236
Sep	1395	594	213
Oct	497	317	219
Nov	411	313	214
Dec	912	201	201

Northbound

	Monthly Demand [unit]		
	PAX	**CAR**	**TRUCKS**
Jan	1000	188	254
Feb	268	105	242
Mar	272	97	287
Apr	510	220	273
May	497	243	275
Jun	576	263	289
Jul	1809	517	315
Aug	2416	680	321
Sep	1339	483	297
Oct	469	202	289
Nov	199	131	274
Dec	248	308	287

HOME

Figure 21 – Passenger, car, and cargo distribution [32]

[31] Source: Project numerical tool, Author's elaboration
[32] Source: Project numerical tool, Author's elaboration

The demands are calculated as explained previously in section 2.4 Traffic and seasonality. Further, the user can also require the tool to create graphs of the demand distribution throughout the year, comparing the ship's capacity with the demand. This maximum capacity will be calculated using parameters defined ahead in the ship's design parameters, using the equations previously demonstrated in this report.

In the graphs illustrated in Figure 22 for the southbound voyages, the monthly capacities of the vessel are expressed by the lines and the user can see if the number of trips is sufficient in most months of the year to supply the route demand, the same can be done for the Northbound trip.

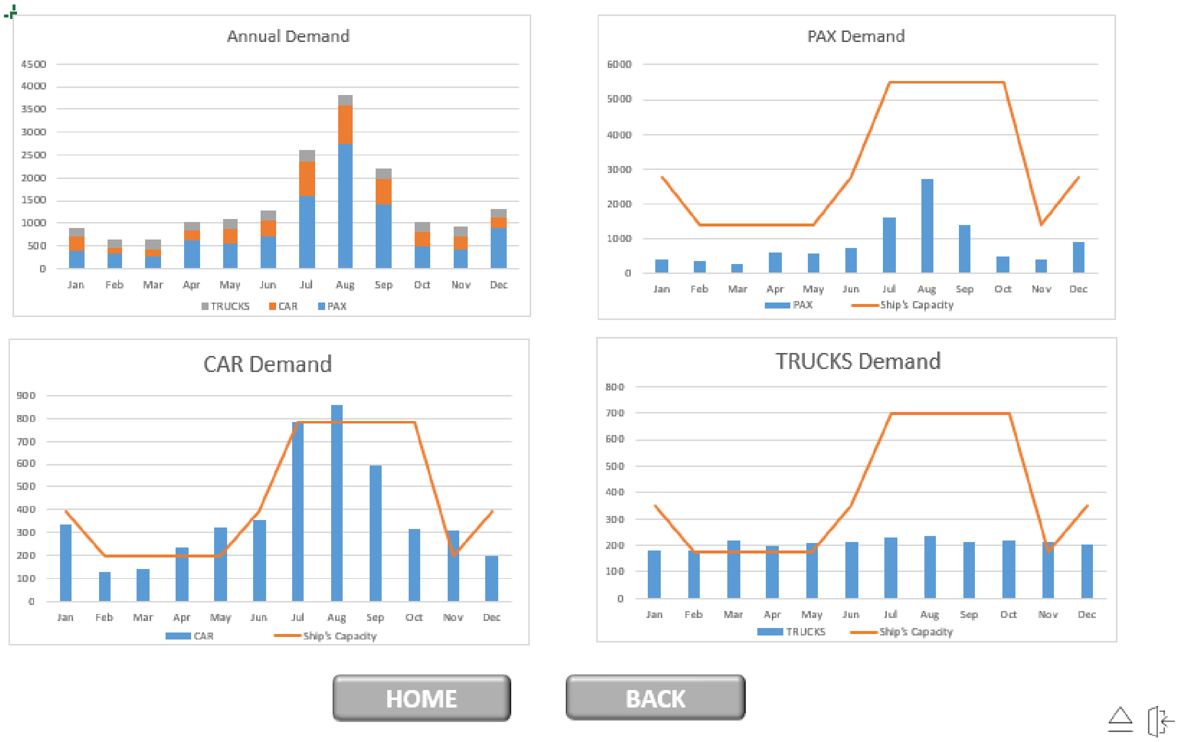
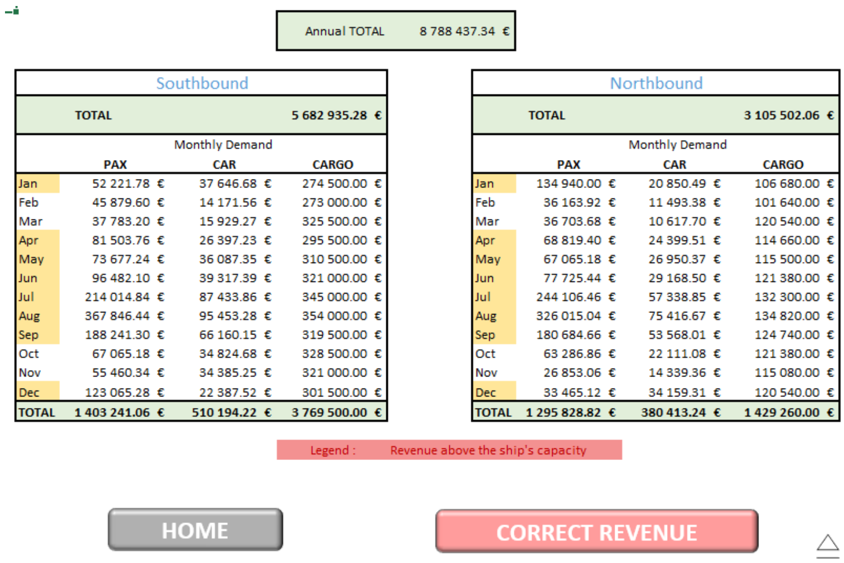


Figure 22 - Southbound demand graphs [33]

In the example illustrated in the image above, it is possible to see that the ship's capacity is lower than the car's and truck's demand for some months; So, in order to fit the capacity with the specific demand, it is necessary to increase the number of trips in the first user's panel of the numerical tool, as previously shown in Figure 20.

The same idea can be applied to the revenue of the operation, the user can also see the revenue calculated for each month and later see its distribution along the year and in its total, as illustrated in Figure 23 and Figure 24, respectively.

[33] Source: Project numerical tool, Author's elaboration



Southbound			
TOTAL			5 682 935.28 €
	Monthly Demand		
	PAX	CAR	CARGO
Jan	52 221.78 €	37 646.68 €	274 500.00 €
Feb	45 879.60 €	14 171.56 €	273 000.00 €
Mar	37 783.20 €	15 929.27 €	325 500.00 €
Apr	81 503.76 €	26 397.23 €	295 500.00 €
May	73 677.24 €	36 087.35 €	310 500.00 €
Jun	96 482.10 €	39 317.39 €	321 000.00 €
Jul	214 014.84 €	87 433.86 €	345 000.00 €
Aug	367 846.44 €	95 453.28 €	354 000.00 €
Sep	188 241.30 €	66 160.15 €	319 500.00 €
Oct	67 065.18 €	34 824.68 €	328 500.00 €
Nov	55 460.34 €	34 385.25 €	321 000.00 €
Dec	123 065.28 €	22 387.52 €	301 500.00 €
TOTAL	1 403 241.06 €	510 194.22 €	3 769 500.00 €

Northbound			
TOTAL			3 105 502.06 €
	Monthly Demand		
	PAX	CAR	CARGO
Jan	134 940.00 €	20 850.49 €	106 680.00 €
Feb	36 163.92 €	11 493.38 €	101 640.00 €
Mar	36 703.68 €	10 617.70 €	120 540.00 €
Apr	68 819.40 €	24 399.51 €	114 660.00 €
May	67 065.18 €	26 950.37 €	115 500.00 €
Jun	77 725.44 €	29 168.50 €	121 380.00 €
Jul	244 106.46 €	57 338.85 €	132 300.00 €
Aug	326 015.04 €	75 416.67 €	134 820.00 €
Sep	180 684.66 €	53 568.01 €	124 740.00 €
Oct	63 286.86 €	22 111.08 €	121 380.00 €
Nov	26 853.06 €	14 339.36 €	115 080.00 €
Dec	33 465.12 €	34 159.31 €	120 540.00 €
TOTAL	1 295 828.82 €	380 413.24 €	1 429 260.00 €

Figure 23 - Potential revenue distribution [34]

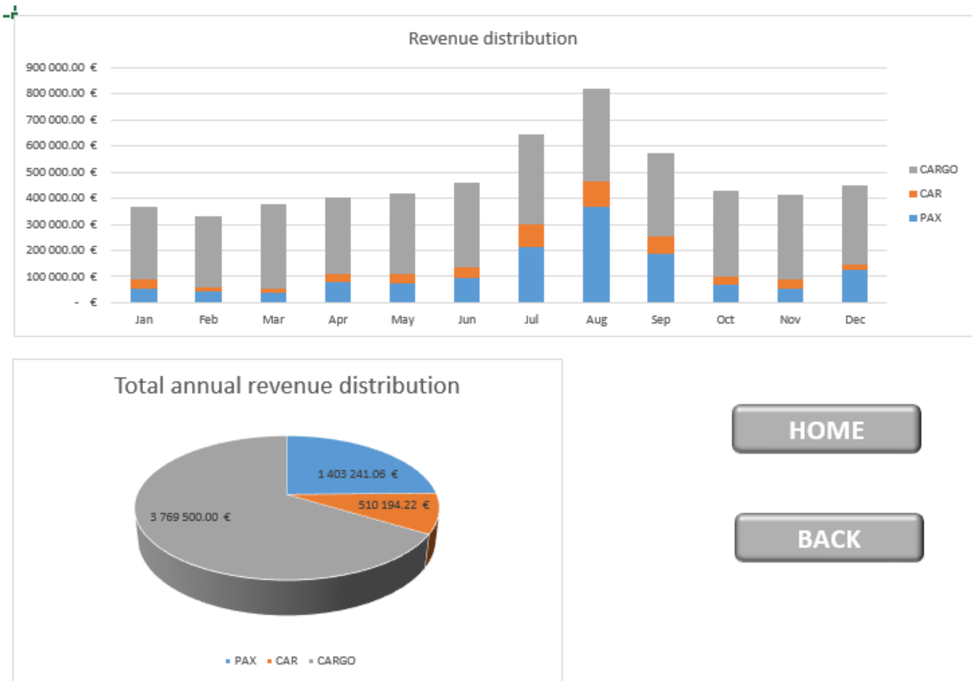


Figure 24 - Revenue distribution for the southbound trip [35]

Notice that before it, the distribution of the revenue is created, and the total revenue must be corrected according to the maximum capacity of the ship, because the demand can be higher than the haulage

[34] Source: Project numerical tool, Author's elaboration
[35] Source: Project numerical tool, Author's elaboration

capacity of the ship, and the extra revenue cannot be considered in the further calculations of the numerical methodology. This correction can be made by clicking on the “Correct Revenue” button.

Having the voyage parameters defined, the user passes to the design parameters, in the user’s interface the design variables are defined in the grey boxes, as illustrated in Figure 25.

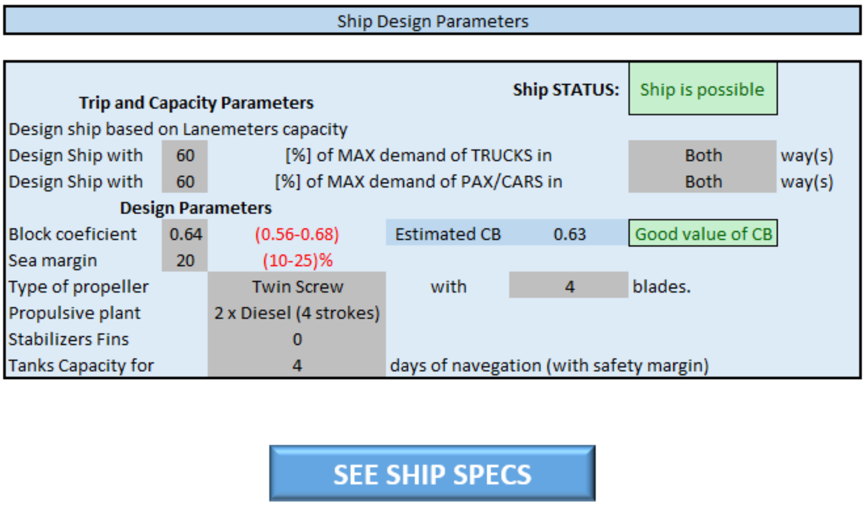


Figure 25 - Ship's design user’s control panel [36]

In this step, the carrying capacity of the ship is defined by the user as a percentage of the maximum annual demand mapped by the methodology, allowing the possibility to fit the vessel for both seasons, not having great operating losses during low season or revenue losses by not supplying the required demand during high season.

The tool also informs the user if the ship’s sizing parameters conform to the physical restrictions of the route, namely maximum main particulars, minimum capacities, and minimum gross tonnage, as is possible to see in the “Ship’s STATUS” box. With a possible ship, the user is led to see the main specifications of the ship, including the new building price estimation, as shown in Figure 26.

[36] Source: Project numerical tool, Author’s elaboration

Main Particulars		
LOA	175.3	[m]
LPP	160.7	[m]
B	25.0	[m]
Design Draught	6.1	[m]
Maximum Draught	6.4	[m]
Depth until weater deck	15.0	[m]
Service speed	21	[knots]
GT	36706	-
Δ	17275	[ton]
Crew	*33*	-
DWT	*13217*	[ton]

Capacity		
Passangers capacity	751	[pax]
Lanemeters	2062.5	[m]
Number of seats	108	[seats]
Number of 2px cabins	14	[cabins]
Number of 4px cabins	27	[cabins]
Number of trucks	91	[trucks]
Number of cars	102	[cars]

Basic Hydrostatics		
Freeboard calculation	2.40	[m]
Wetted Surface	4711	[m²]
Total Resistance	1619	[kN]
Buoyance Center Ordinate	3.51	[m]
Transverse Metacentric Radius	8.62	[m]
Metacentric Height (KM)	12.68	[m]
Metacentric Height (GMT)	1.15	[m]
Roll Period	10	[s]
Buoyancy Center abscissa (LCB)	-2%	[% Lpp AV MS]

Engine and Propeller		
PMCR estipulated	29340.3	[kW]
Admiralty Formula	15472	[kW]
Eletric Power	6817	[kW]
Apparent power of the genset	8521	[kVA]
Propeller diameter	4.28	[m]
Optimum revolution Rate	276	[rpm]
Tip velocity	62	[m/s]

Design Coefficients		
Block Coefficient	0.635	-
Prismatic Coefficient	0.65	-
LPP/B	6.43	OK
B/T	4.11	OK
LPP/T	26.43	OK
L/D	10.73	OK
LPP/VOL^(1/3)	6.27	OK

Total Shipbuilding Price			
Total Building Cost		91.38	*[m USD]*
Kb	*10%*	*Shipyard profit margin*	*[-]*
Ka	*8%*	*Owner Extras Costs*	*[-]*
Final Investment		**108.56**	***[m USD]***

HOME

Figure 26 - Sized ship specifications [37]

Notice that the numerical tool checks the main principals' calculations, by checking if the adimensional parameters of the sized ship are within the average values for similar Ro-Pax ships, according to Kristensen and Psaraftis (2016) statistical studies.

Having both, voyage and ship defined, the user passes to the economic parameters user's control panel, which encompasses investment and external economic variables. Figure 27 illustrates the user's interface for the definition of such variables.

Other Parameters					
			Currency		
VLSFO price	300	[USD/MT]	€ to USD	1.18	[€/USD]
MDO price	323	[USD/MT]			
Time in Portimão	8	[h]			
Time in Funchal	8	[h]			
Discount rate	8%				
Owner Investment	40%	**Payback period always set as 8 years*			
Garantees of investment	2%	*** Life of the ship is set as 20 years of operation*			
Interest Rate	1%				
Scrap Value	$ 15 562 156.00	[USD]			
Taxes	20%				

SEE COSTS AND CASH FLOW

Figure 27 - Economic parameters user's control panel [38]

[37] Source: Project numerical tool, Author's elaboration
[38] Source: Project numerical tool, Author's elaboration

Finally, after defining those, the user is led to see all costs calculations, costs distributions, and cash flow of the operation, having both options, shipbuilding investment or annuity investment, for the capital investment, previously explained in the section in 3.3 Costs structure for Ro-Pax ships.

Figure 28, Figure 29, and Figure 30 show examples of operating, operating added to fuel, and operating added to voyage (fuel and ports) annual costs distributions that are presented to the user, respectively.

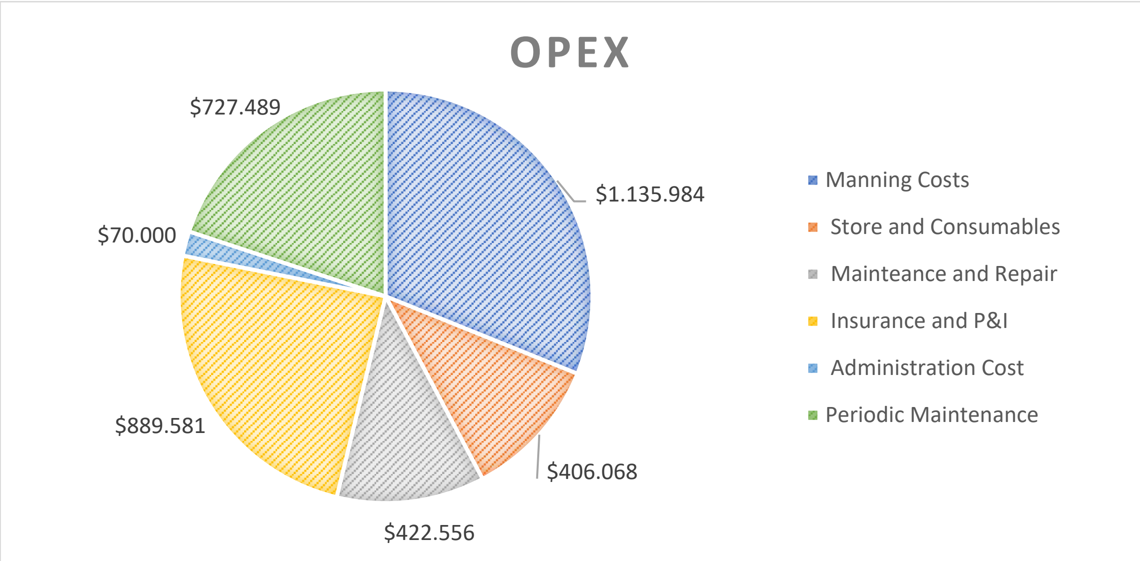


Figure 28 - Example of operating costs distribution [39]

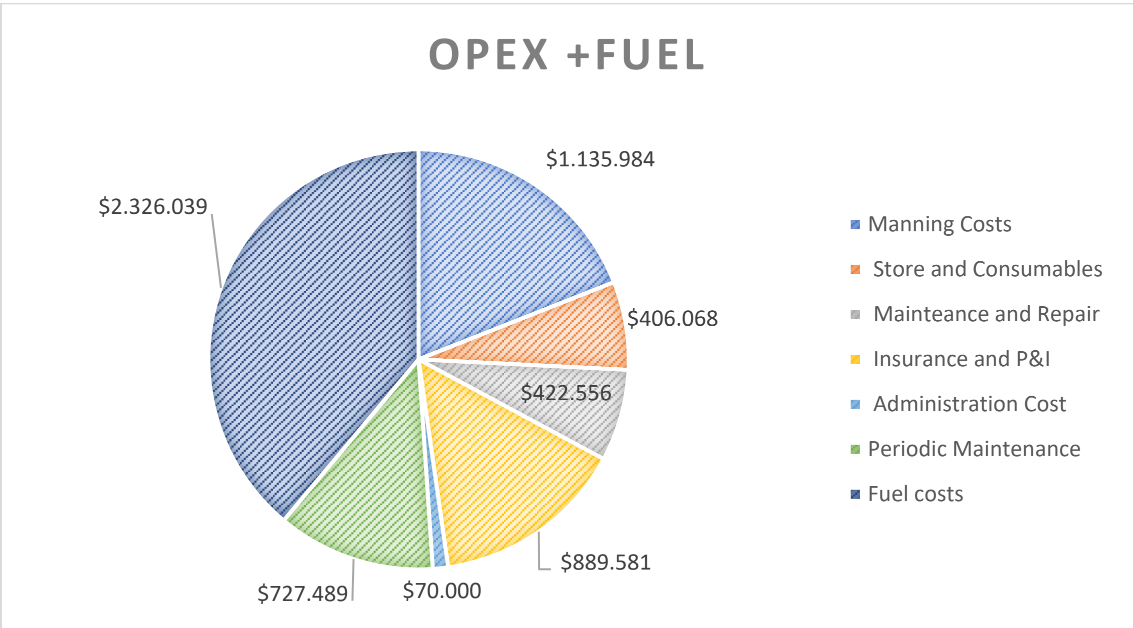


Figure 29 - Example of operating added to fuel costs distribution [40]

[39] Source: Project numerical tool, Author's elaboration
[40] Source: Project numerical tool, Author's elaboration

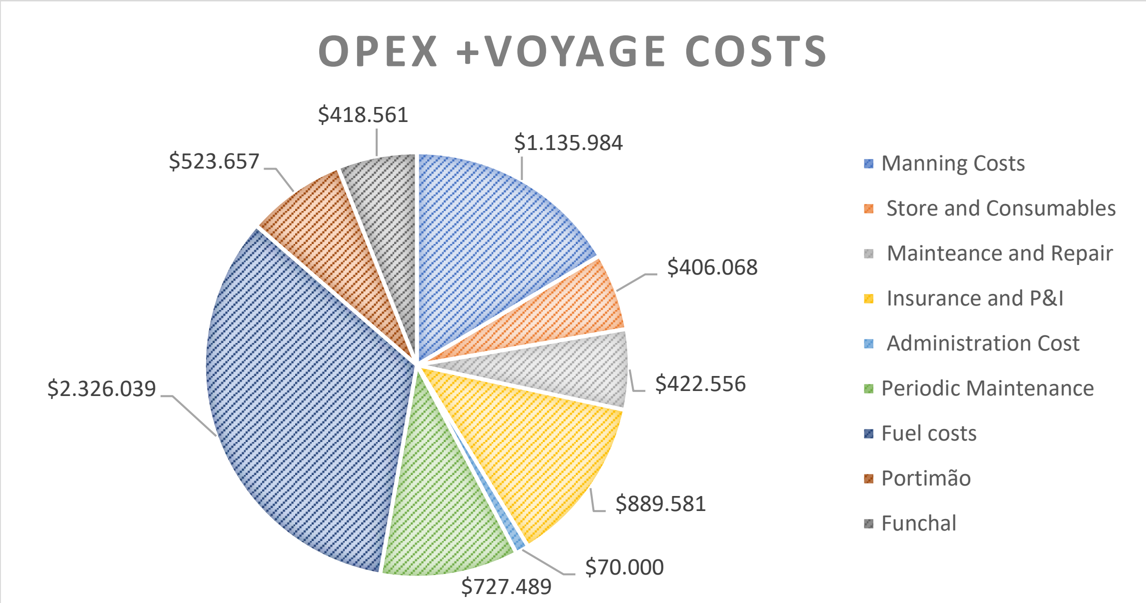


Figure 30 - Example operating added to voyage costs distribution [41]

Not only with the annual costs of the operation, but the user is also presented with the full operation cash flow along its 20 years. As said before the capital investment can be calculated in two different ways, by building investment and by chartering, leading to two different global cash flows, but both distributions are presented to the user, illustrated respectively in Figure 31 and Figure 32.

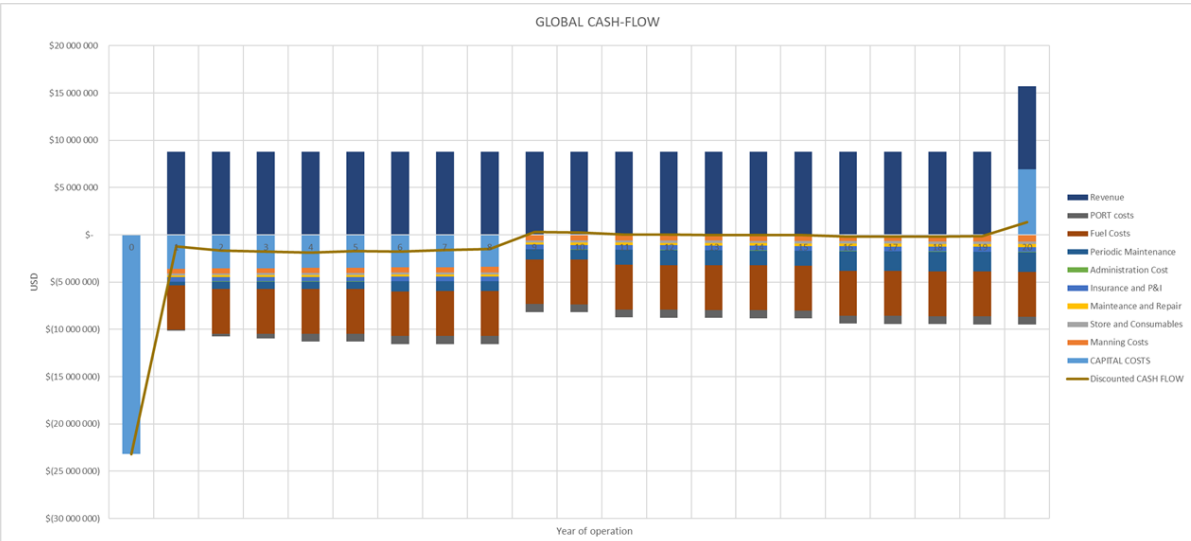


Figure 31 - Example of global cash flow with building investment [42]

[41] Source: Project numerical tool, Author's elaboration
[42] Source: Project numerical tool, Author's elaboration

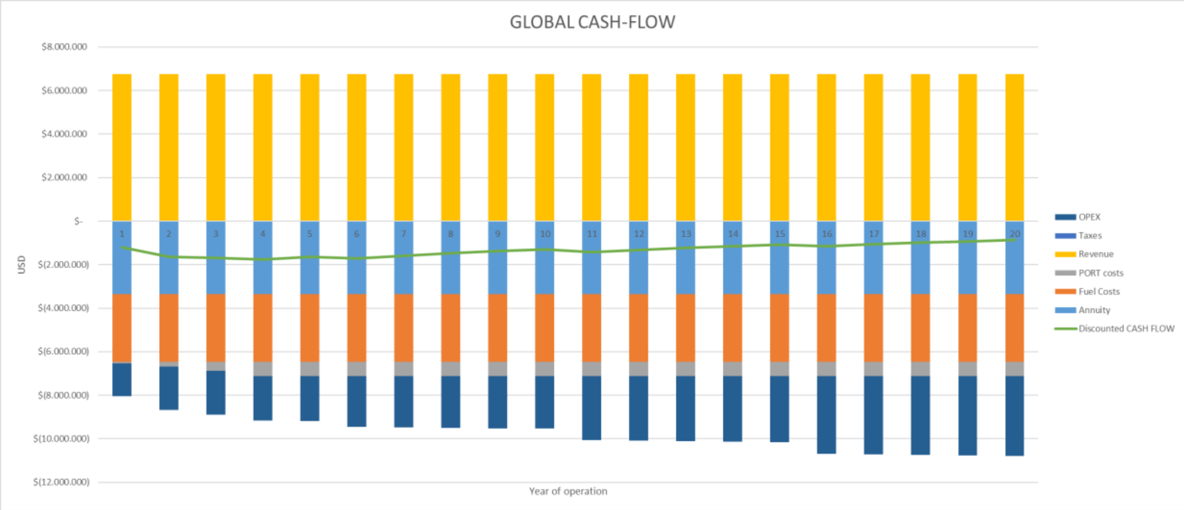


Figure 32 - Example of global cash flow chartering the vessel [43]

[43] Source: Project numerical tool, Author's elaboration

4. CASE STUDY

4.1 Methodology correction analysis

In order to trust the numerical tool, it is necessary to measure the accuracy when sizing the vessel to the voyage. Therefore, the numerical tool is forced to size different vessels for different lanemeters and passengers' capacities, trying to identify the parameters calculated that differ from the usual values.

Taking into consideration the limitations of the formulae used in the tool, namely regarding the expressions used according to Kristensen and Psaraftis (2016), which are limited to high-density cargo Ro-Pax ships, having on average a maximum passenger capacity of $1{,}500$. Only vessels with less passenger capacity will be used during the creation of the corrections equations.

The two main characteristics used to choose the ships, from the database created, to be used in the correction procedure, are the lanemeters, and the passenger capacity. Table 11 shows the characteristics of the ships used for the corrections in the methodology.

Table 11 - Ship's characteristics [44]

Ship	Lanemeters [m]	Passenger capacity [pax]
1	364	1500
2	376	700
3	450	600
4	730	600
5	1150	600
6	1235	500
7	1500	966
8	1908	1200
9	2250	800
10	3355	1360

Forcing the tool to size vessels with the capacities above mentioned, the parameters calculated are compared with the real values and it is possible to notice that for the main particulars the numerical tool has good accuracy, but regarding deadweight, passenger capacity, main engine power, and auxiliary power the numerical tool is inaccurate. Having differences ranging up to $300\,\%$, urges a need for corrections of those parameters because some interfere directly with the financial analysis of the operation, especially the powers and the passenger capacity. Figure 33 illustrates the deviation distribution of the characteristics calculated from the real values.

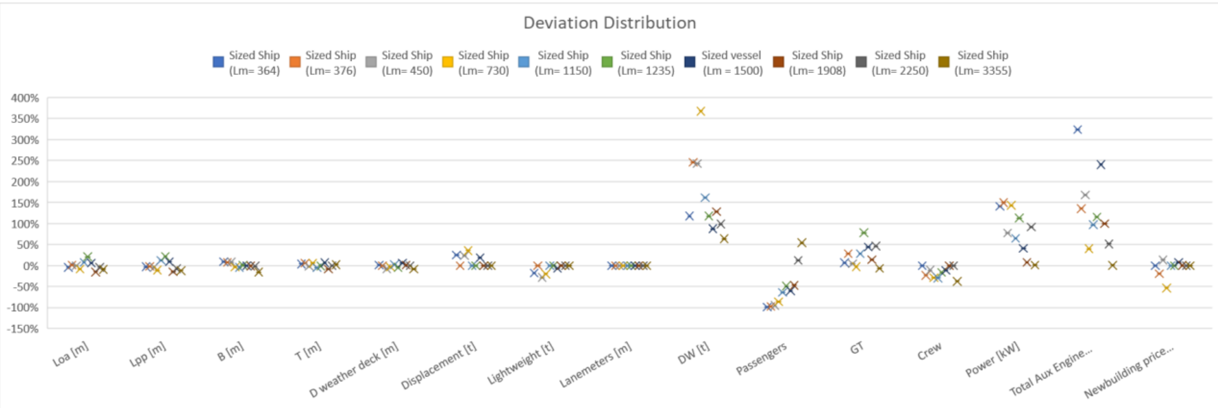


Figure 33 - Deviation distribution [45]

Having all deviations calculated, for each parameter, the divergences are plotted, and different regressions are used to best correct the model in order to approximate it with reality. All corrections are considered as functions of the lanemeter capacity wanted, following the equation (91):

$$F(x) = f(x) + C(Lmt) \tag{91}$$

[44] Source: Author’s elaboration
[45] Source: Author’s elaboration

Where $F(x)$ is the parameter calculated with the correction, $f(x)$ is the value calculated by the methodology before the correction, and $C(Lmt)$ is the correction as a function of the lanemeter capacity. The equations used are listed below in Table 12:

Table 12 - Correction equations as a function of the lanemeter capacity [46]

Parameter	Equation for correction
DW [t]	$y = 1643.5 \times ln(Lmt) - 6335.9$
Passengers	$y = 2 \times 10^{-7} \times Lmt^3 - 0.001 \times Lmt^2 + 1.803 \times Lmt - 1472.3$
Power [kW]	$y = -1 \times 10^{-6} \times Lmt^3 + 0.0053 \times Lmt^2 - 7.2807 \times Lmt + 6599.9$
Total Aux Engine power [kW]	$y = -0.0009 \times Lmt^2 + 7.2475 \times Lmt - 20938$

Having in hands all necessary corrections, they are applied in the mathematical tool and again the same ships are sized and compared with their real parameters. Figure 34 shows the after correction deviation distribution, it is possible to see that the accuracy of the model has improved, but still has large differences, especially regarding the auxiliary power prediction, perhaps because of the difficulty of predicting the hoteling consumption of Ro-Pax ships, considering the large range of passengers capacity and that the auxiliary power from the specifications of the vessels can consider not just the generator set, but also the shaft generators and the emergency generators.

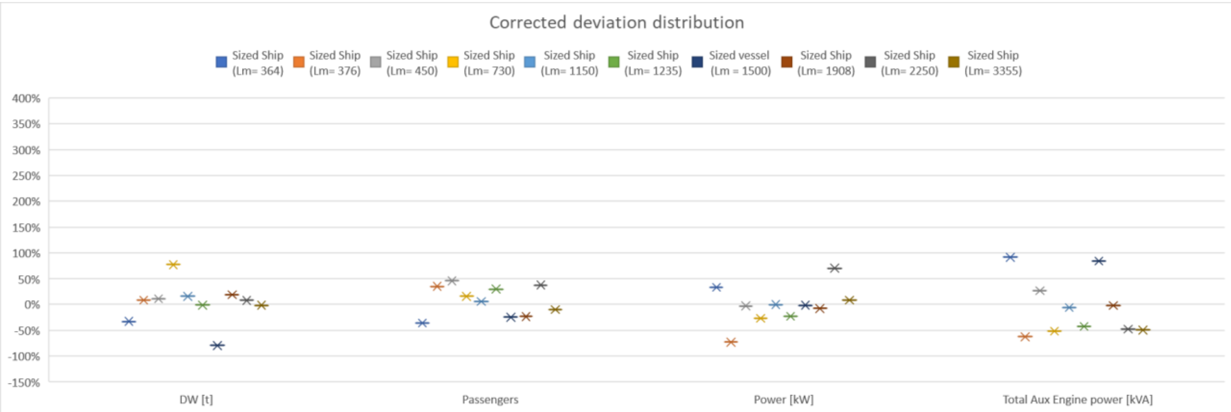


Figure 34 - Corrected deviation distribution [47]

4.2 Comparison with ships in service in the route

In this section, the objective is to compare if it is more profitable when operating the route to use a chartered vessel, similar to the one operated previously, or to build a new ship suitable for the operation. Therefore, the numerical tool will be used to simulate two scenarios:

[46] Source: Author's elaboration
[47] Source: Author's elaboration

- The operated vessel in the route (same lanemeter capacity), with annuity CAPEX investment,
- A sized vessel according to the demand of the route (using the same velocity and similar haulage capacity), with the new building investment.

4.2.1 Chartered Ro-Pax ship

For the first scenario, the methodology will simulate a ship with the same lanemeters capacity as the ship previously operated on the route, using the same freight rate applied for the voyage, in an attempt to replicate similar conditions as the previous operations of the route. Figure 35 shows the passenger's and car's fares and freight rates operated in 2011, which will be used as input in the numerical tool.

PORTIMÃO / FUNCHAL		
	IDA & VOLTA	POR TRAJECTO
Poltrona adulto (por pessoa)	156,00 €	78,00 €
Poltrona criança (por pessoa)	78,00 €	39,00 €
Animais domésticos	6,02 €	3,01 €
Camarote duplo (por camarote)	620,00 €	310,00 €
Camarote quádruplo ocupado por 1 pax (por camarote)	880,00 €	440,00 €
Camarote quádruplo ocupado por 2 paxs (por camarote)	920,00 €	460,00 €
Camarote quádruplo ocupado por 3 paxs (por camarote)	930,00 €	465,00 €
Camarote quádruplo ocupado por 4 paxs (por camarote)	1.240,00 €	620,00 €
Bicicletas	12,00 €	6,00 €
Motos	150,00 €	75,00 €
(V) Veículo < 1,85 m. altura e/ou < 4,85 m. comprimento	200,00 €	100,00 €
(V) Veículo < 2 m. altura e/ou < 5 m. comprimento	200,00 €	100,00 €
(X) Veículo > 2,00 m. altura e/ou > 5,00 m. comprimento	540,00 €	270,00 €
(VR) Veículo + reboque < 1,85 m. altura e/ou < 4,85 m. comprimento	750,00 €	375,00 €
(XR) Veículo ou reboque com > 2,00 m. altura e/ou > 5,00 m. comprimento	850,00 €	425,00 €

Figure 35 – Tariffs applied by Naviera Armas, in 2011 [48]

As the figure shows, in the previous operation regarding the tariffs applied to passenger's and the car's the tickets do not take into consideration the direction of the trip, but only if it is a one-way ticket or not. Knowing this, the input freight rate for the methodology will be the same for high and low seasons.

For the trucks, the operators used to charge € $110.00/meter$ if the vehicle is carrying goods, otherwise € $30.00/meter$. Therefore, the inputs are:

- € 78.00 for non-resident passenger,
- € 100.00 for non-resident car,
- € 1496.00 for the full truck,
- € 420.00 for the empty truck.

[48] Source: AGENCIA BRAVATOUR

According to Quintal (2013), the approximated tariff operated by container carriers for the haulage of an FEU from Continental Portugal to the RAM is € $1\ 925{,}00$, comparing this value with the freight rate above mentioned, it is possible to see that the freight operated is very competitive in the market.

The ship's speed is set at 21 knots, based on the service speed specified of the operated vessel. Finally, the number of trips for each month is assumed to be the minimum to supply most of the demand for trucks southbound (being the majority of the income), but also respecting the government request of 24 trips between the 1st of June and 15th of September. The distribution of trips among the year is as follows in Table 13. In this sense, it is settled one round trip per week throughout the year.

Table 13 - Monthly departures for the simulation [49]

Month	Monthly departures from Portimão
Jan	4
Feb	4
Mar	4
Apr	4
May	4
Jun	4
Jul	4
Aug	4
Sep	4
Oct	4
Nov	4
Dec	4

For the design parameters, it settles the lanemeter capacity of the ship as $1{,}500$, it is also defined the block coefficient as $0{,}64$, a sea margin of 20%, the propulsion system is configured with twin screw propellers, with 4 blades, the ship will have 2 diesel four strokes main engines, with two stabilizers fins and with a tank capacity of 4 days of navigation.

The ship generated by the numerical tool, for $1{,}500$ lanemeters of capacity, is illustrated in Figure 36. Having a first look, just analyzing the main dimensions of the required vessel, it is possible to notice that both ships are different. Meanwhile, Figure 37 shows the specifications of the *Vólcan de Tijarafe*, the vessel operated previously in the route.

[49] Source: Project numerical tool, Author's elaboration

Main Particulars

LOA	163.2	[m]
LPP	149.5	[m]
B	24.1	[m]
Design Draught	5.9	[m]
Maximum Draught	6.2	[m]
Depth until weater deck	14.4	[m]
Service speed	22	[knots]
GT	21956	-
Δ	14999	[ton]
Crew	33	-
DWT	5848	[ton]

Capacity

Passangers capacity	726	[pax]
Lanemeters	1500	[m]
Number of seats	224	[seats]
Number of 2px cabins	28	[cabins]
Number of 4px cabins	56	[cabins]
Number of trucks	54	[trucks]
Number of cars	141	[cars]

Basic Hydrostatics

Freeboard calculation	2.21	[m]
Wetted Surface	4234	[m²]
Total Resistance	1726	[kN]
Buoyance Center Ordinate	3.38	[m]
Transverse Metacentric Radius	8.24	[m]
Metacentric Height (KM)	12.21	[m]
Metacentric Height (GMT)	1.07	[m]
Roll Period	10	[s]
Buoyancy Center abscissa (LCB)	-3%	[% Lpp AV MS]

Engine and Propeller

PMCR estipulated	23069.4	[kW]
Admiralty Formula	16190	[kW]
Eletric Power	1651	[kW]
Apparent power of the genset	2063	[kVA]
Propeller diameter	4.14	[m]
Optimum revolution Rate	269	[rpm]
Tip velocity	58	[m/s]

Design Coefficients

Block Coefficient	0.64	-
Prismatic Coefficient	0.65	-
LPP/B	6.22	OK
B/T	4.10	OK
LPP/T	25.49	OK
L/D	10.37	OK
LPP/VOL^(1/3)	6.11	OK

Total Shipbuilding Price

Total Building Cost		81.45	[m USD]
Kb	10%	Shipyard profit margin	[-]
Ka	8%	Owner Extras Costs	[-]
Final Investment		**96.76**	**[m USD]**

HOME

Figure 36 - Sized ship for 1500 lanemeter capacity [50]

Main Particulars:

Length Overall: 154.51 m
Length between Perpendiculars: 137.00 m
Moulded Breadth: 24.20 m
Depth to Main Deck: 8.53 m
Extreme Draught: 5.80 m
Design Moulded Draught: 5.50 m
Deadweight at 5.50 m approx.: 3350 T
Service Speed: 23 knots
Range at Service Speed: 2200 miles

Classification:

I✠Hull✠MACH Ro-Ro passenger ship, Unrestricted navigation, AUT-UMS, MON-SHAFT, INWATER SURVEY

Propulsion & Manoeuvring Equipment:

Main Engines: 2 x 11700 kW at 500 rpm
Generating Sets: 2 x 1200 kW at 1000 rpm
Emergency Gensets: 1 x 250 kW at 1500 rpm
2 x CP Main Propellers, 4 Blades, 4200 mm Diameter
2 x 1000 kW CP Bow Tunnel Thrusters

Cargo Capacity:

Max. Capacity (crew + passengers): 1000 people
No. of Cabins: 46 x 4 pax cabins, 8 x 2 pax cabins and 8 x 2 pax cabins for disabled people
No. of Cargo Decks: 2 + 1 cardeck
Cargo Capacity with Cars and Trailers: 174 cars and 57 trailers
Cargo Capacity only with Trailers: 80 Trailers

Cargo Equipment:

2 Stern Ramp-Coors: 16 m length x 8 m wide
1 movable Cardeck in Garage between Upper Deck No. 4 and Deck No. 6

Tanks Capacity:

Fuel-Oil Capacity: 616 m^3
Diesel-Oil Capacity: 92 m^3
Lub. Oil Capacity: 54 m^3
Fresh Water Capacity: 93 m^3
Ballast Water Capacity: 1826 m^3

Figure 37 - Specifications of Ro-Pax Vólcan de Tijarafe ferry, operated in the route [51]

It is possible to observe that the vessel generated by the numerical tool is larger than the operated ship, probably because most Ro-Pax ships have special equipment for carrying low-weight rolling cargo,

[50] Source: Project numerical tool, Author's elaboration
[51] Source: Hijos de J. Barreras

namely internal car decks, that optimized the lanemeter capacity without raising the overall length of the ship, and in the numerical tool this feature is not considered. Analyzing the general arrangement of the hull of the sister-ship of the operated vessel, illustrated in Figure 38, it is possible to observe such structures around the midship area, in the second deck of cargo, pointed out in the figure below.

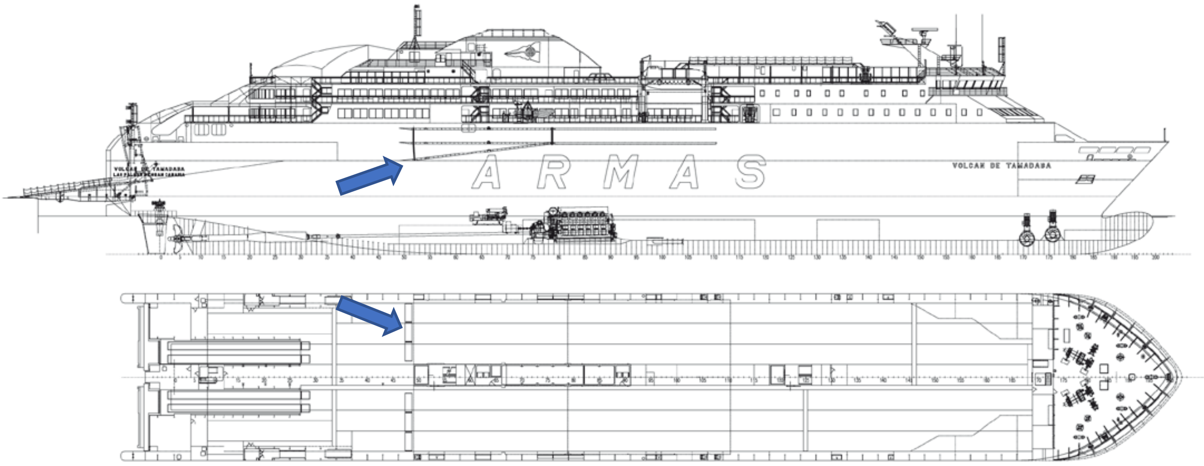


Figure 38 - General Arrangement of the operated vessel [52]

Now, having all parameters of the sized vessel calculated, it is possible to analyze the accuracy of the tool for this specific case, show below in Table 14.

[52] Source: Hijos de J. Barreras, adapted by the Author

Table 14 - Specifications of the operated and sized vessel, with deviations in % [53]

	Operated Vessel (sister-ship)	**Sized vessel (Lanemeters = 1500) Corrected**	%
Loa [m]	154.51	163.20	6%
Lpp [m]	137.00	149.52	9%
B [m]	24.20	24.05	-1%
T [m]	5.50	5.87	7%
D weather deck [m]	13.55	14.42	6%
Vs [knots]	21.70	22.00	1%
Displacement [t]	12650	14999	19%
Lightweight [t]	9250	9151	-1%
Lanemeters [m]	1500	1500	0%
DW [t]	3400	5848	72%
Passengers	966	726	-25%
GT	19976	21956	10%
Crew	34	33	-3%
Power [kW]	23400	23069	-1%
Total Aux Engine power [kW]	2400	1651	-31%
Newbuilding price [m USD]	90.0	96.76	8%

It is possible to observe that only four calculated parameters are imprecise compared with the real ship specifications, namely, deadweight, passenger capacity, auxiliary power, and displacement. Being the biggest difference of the DWT, knowing that it does not interfere with the financial calculations, no further corrections are needed, also applicable for the displacement.

Regarding passenger capacity, when analyzing the ship's haulage capacity of transporting passengers and the monthly demand (considering one voyage per week), it is enough to supply it, even with a lower capacity compared with the real ship.

Finally, about the auxiliary power, considering that before the corrections made in the model, the deviation was $240\ \%$ and now is -31%, and being a complicated parameter to predict, considering the different arrangements possible for auxiliary, shaft, and emergency generator, the value calculated can be acceptable with no longer corrections, even being relevant for the fuel consumption of the ship, does not cause great divergence in the global financial analysis.

With the objective to verify if the vessel sized in this scenario supply's the total capacity of the route, both demands (southbound and northbound) are added and compared with the ship's haulage capacity

[53] Source: Author's elaboration

for each type of cargo (passengers, cars, and trucks). Figure 39, Figure 40, and Figure 41 show the global demand compared with the haulage capacity of the ship sized.

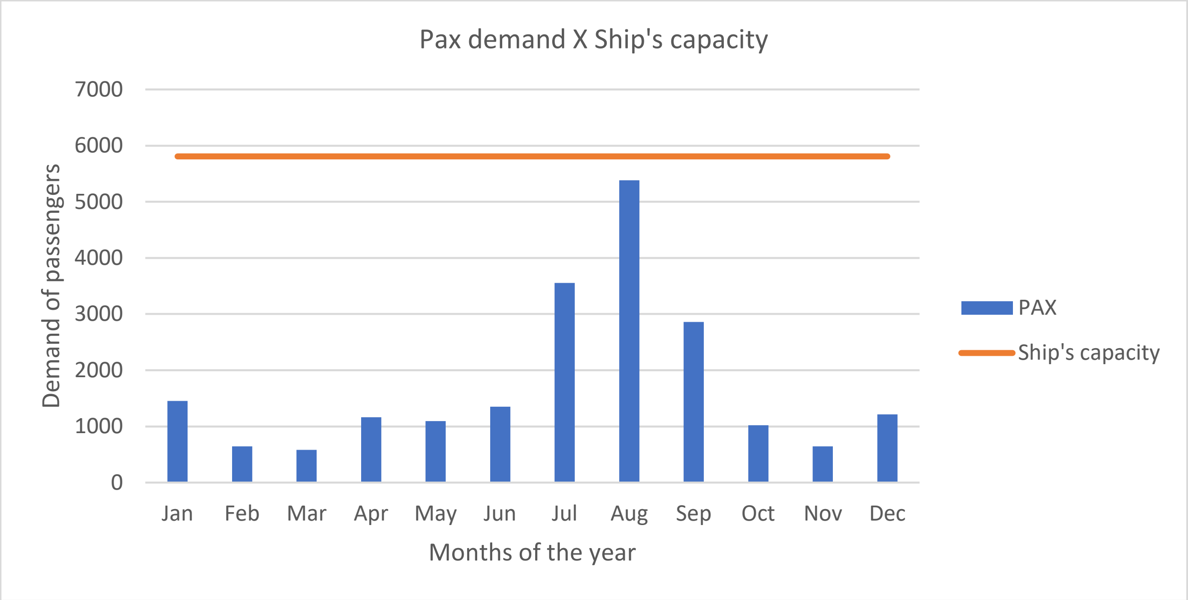


Figure 39 - PAX global demand compared with the ship's capacity [54]

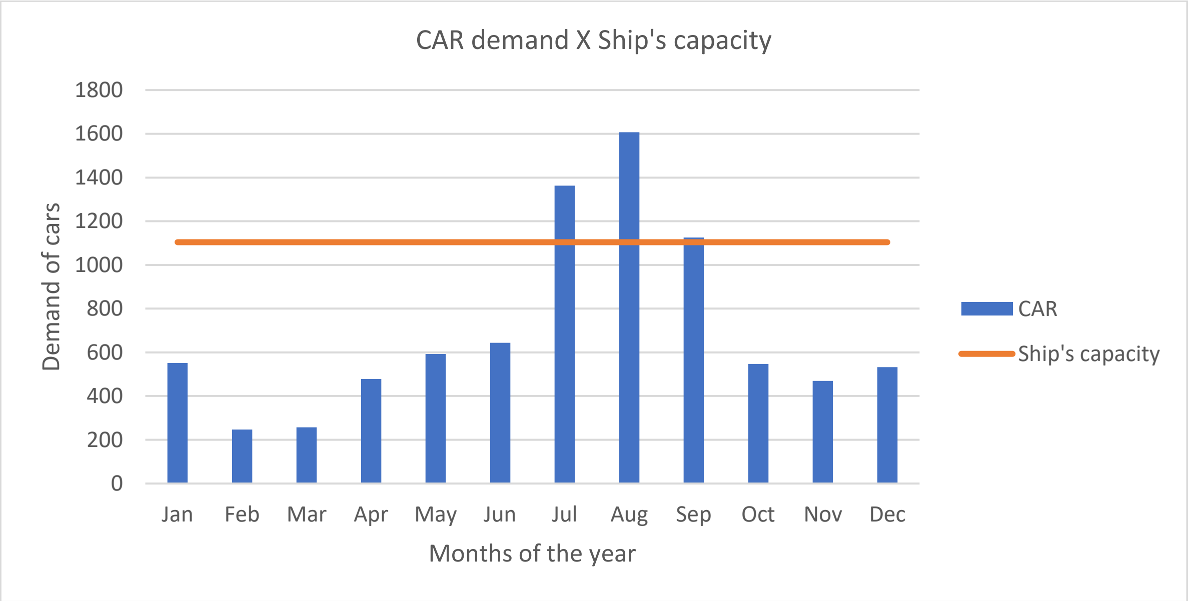


Figure 40 – Cars global demand compared with the ship's capacity [55]

[54] Source: Project numerical tool, Author's elaboration
[55] Source: Project numerical tool, Author's elaboration

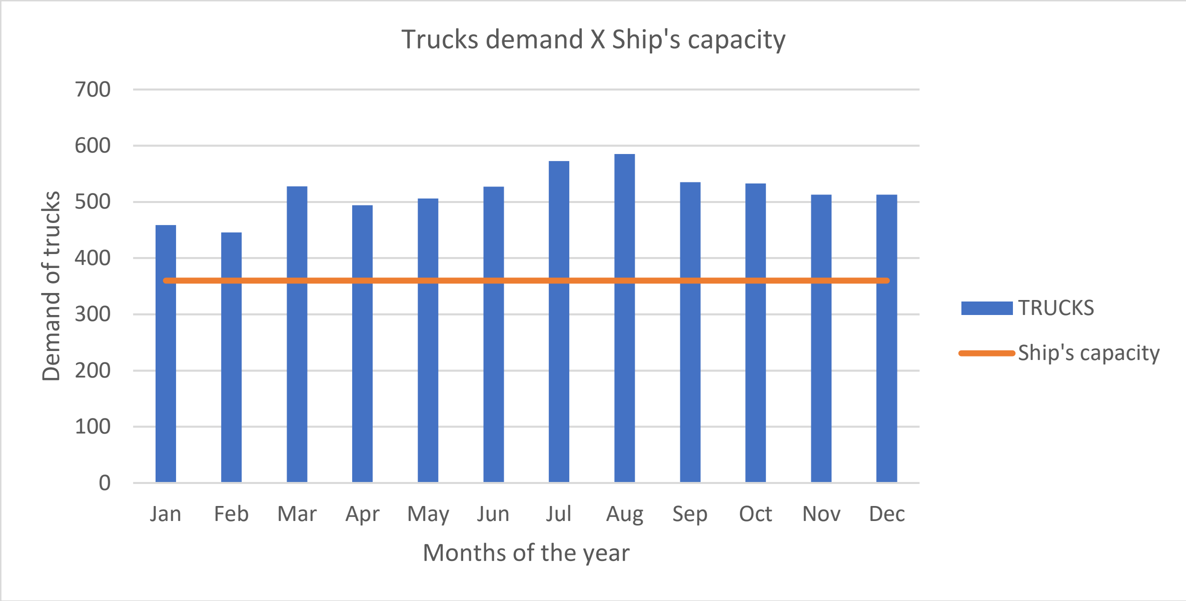


Figure 41 - Trucks global demand compared with the ship's capacity [56]

In order to quantify the haulage capacity of the ship sized, it is possible to calculate the ratio between the demand and the monthly ship's capacity. Doing so, it is possible to see that in this configuration, the ship supplies 66% of the car's maximum demand and 59% of the truck's maximum demand.

With the ship sized, financial analysis can be done. First defining the parameters in the numerical tool, it is set as bunker prices for both fuels the average price of them in Rotterdam from March 2020 until September of 2020. Moreover, the time in port is set as eight hours for each port, and the investment parameters are set as shown in Table 15. Important to notice that for the case study, the scrap value for both scenarios will be considered as $20\ \%$ of the new building price of the vessels.

Table 15 - Investment parameters defined in the case study [57]

Discount rate	8%
Owner Investment	50%
Guarantees of investment	2%
Interest Rate	1%
Scrap Value [USD]	$20\%\ of\ \$P$
Taxes	20%

As said before, the ship will be considered under a long-time charter, meaning that annuity will represent the charter fee, which includes the capital costs, and added to it, the operating, voyage costs (represented by fuel and port costs), and taxes. Figure 42 shows the global cash flow of the 20 years operation of the first scenario of the case study. As is possible to see, the operation has losses in all the years, after applying the discount rate in the cash flow, it is possible to calculate the Net Present Value

[56] Source: Project numerical tool, Author's elaboration
[57] Source: Author's elaboration

(NPV) of the entire 20 years of operation, the result is exposed in equation (92) below. APPENDIX 4 – Cash Flow of the case study details the total cash flow for both scenarios of the case study.

$$NPV \ = \ \$\,(27.683.511) \qquad [USD] \tag{92}$$

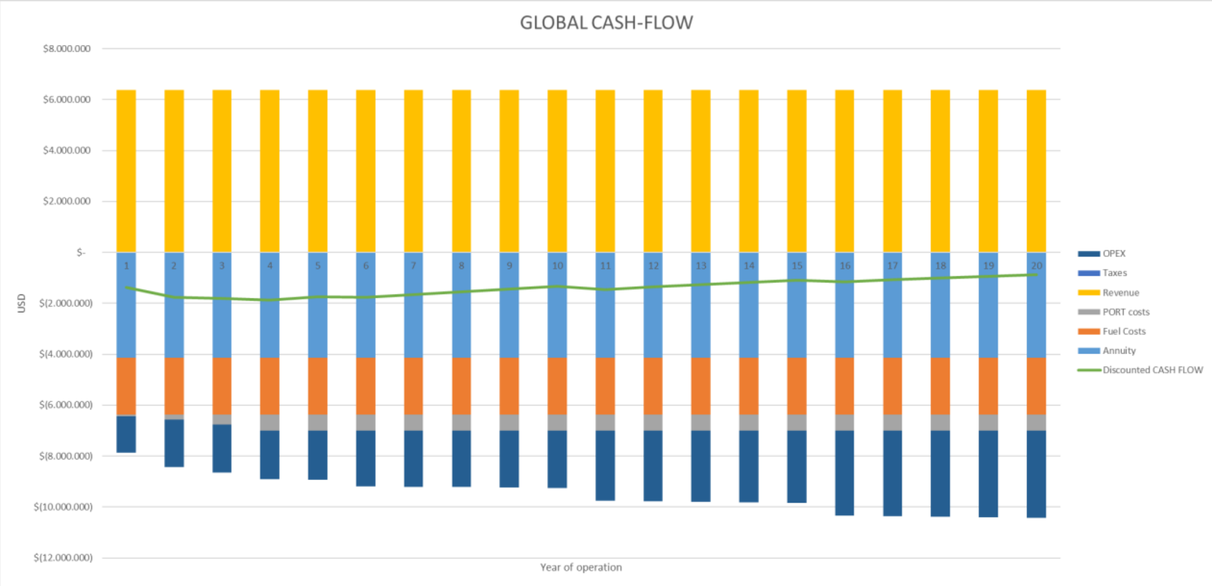


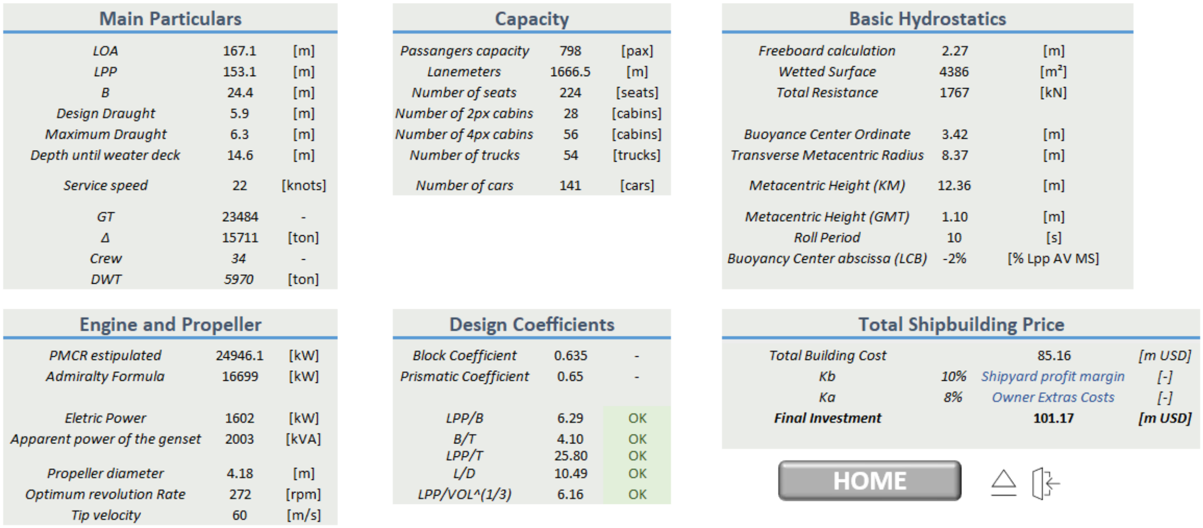
Figure 42 - Global cash flow of the first scenario of the case study [58]

4.2.2 Newbuilt Ro-Pax

Having the first scenario defined and studied, the second can be simulated. Before starting to size the vessel, it is necessary to understand that the vessel, in the numerical tool, can be sized to supply a percentage of the demand. In this scenario the specifications of the ship will be calculated to supply $60\ \%$ of the maximum demand of trucks and cars all year long, trying to approximate this scenario with the first one regarding the haulage capacity of the vessels. Added to that, in this way, during low season the operations will not have unnecessary operating costs and during high season, will not have revenue losses, by not supplying a great part of the demand, especially regarding truck southbound, that is the larger income of the operation.

All voyage and other design parameters are set as the previous scenario, in this way, both vessels will operate under the same circumstances. Figure 43 illustrates the sized ship for the second scenario of the case of study, using the same parameters as the first scenario.

[58] Source: Project numerical tool, Author's elaboration



Main Particulars		
LOA	167.1	[m]
LPP	153.1	[m]
B	24.4	[m]
Design Draught	5.9	[m]
Maximum Draught	6.3	[m]
Depth until weater deck	14.6	[m]
Service speed	22	[knots]
GT	23484	-
Δ	15711	[ton]
Crew	34	-
DWT	5970	[ton]

Capacity		
Passangers capacity	798	[pax]
Lanemeters	1666.5	[m]
Number of seats	224	[seats]
Number of 2px cabins	28	[cabins]
Number of 4px cabins	56	[cabins]
Number of trucks	54	[trucks]
Number of cars	141	[cars]

Basic Hydrostatics		
Freeboard calculation	2.27	[m]
Wetted Surface	4386	[m²]
Total Resistance	1767	[kN]
Buoyance Center Ordinate	3.42	[m]
Transverse Metacentric Radius	8.37	[m]
Metacentric Height (KM)	12.36	[m]
Metacentric Height (GMT)	1.10	[m]
Roll Period	10	[s]
Buoyancy Center abscissa (LCB)	-2%	[% Lpp AV MS]

Engine and Propeller		
PMCR estipulated	24946.1	[kW]
Admiralty Formula	16699	[kW]
Eletric Power	1602	[kW]
Apparent power of the genset	2003	[kVA]
Propeller diameter	4.18	[m]
Optimum revolution Rate	272	[rpm]
Tip velocity	60	[m/s]

Design Coefficients		
Block Coefficient	0.635	-
Prismatic Coefficient	0.65	-
LPP/B	6.29	OK
B/T	4.10	OK
LPP/T	25.80	OK
L/D	10.49	OK
LPP/VOL^(1/3)	6.16	OK

Total Shipbuilding Price			
Total Building Cost		85.16	[m USD]
Kb	10%	Shipyard profit margin	[-]
Ka	8%	Owner Extras Costs	[-]
Final Investment		**101.17**	**[m USD]**

HOME

Figure 43 - Sized ship specifications for the second scenario of the case study [59]

Comparing both ships sized, it is possible to notice that the second scenario vessel is slightly larger than the first one, as shown in Table 16 below. Meaning greater investment for building it and operating it.

Table 16 - Comparison between both sized ships [60]

	Sized vessel (1 scenario)	Sized vessel (2 scenario)	%
Loa [m]	163.2	167.11	2%
Lpp [m]	149.52	153.13	2%
B [m]	24.05	24.35	1%
T [m]	5.87	5.93	1%
D weather deck [m]	14.42	14.60	1%
Vs [knots]	22	22	0%
Displacement [t]	14999	15711	5%
Lightweight [t]	9151	9741	6%
Lanemeters [m]	1500	1667	11%
DW [t]	5848	5970	2%
Passengers	726	798	10%
GT	21956	23484	7%
Crew	33	34	3%
Power [kW]	23069	24946	8%
Total Aux Engine power [kW]	1651	1602	-3%
Newbuilding price [m USD]	96.76	101.17	5%

[59] Source: Project numerical tool, Author's elaboration
[60] Source: Author's elaboration

Again, with the aim to verify if the vessel sized supplies the global demand of the route, the haulage capacity of the ship is compared with the sum of the demand both ways of the trip.

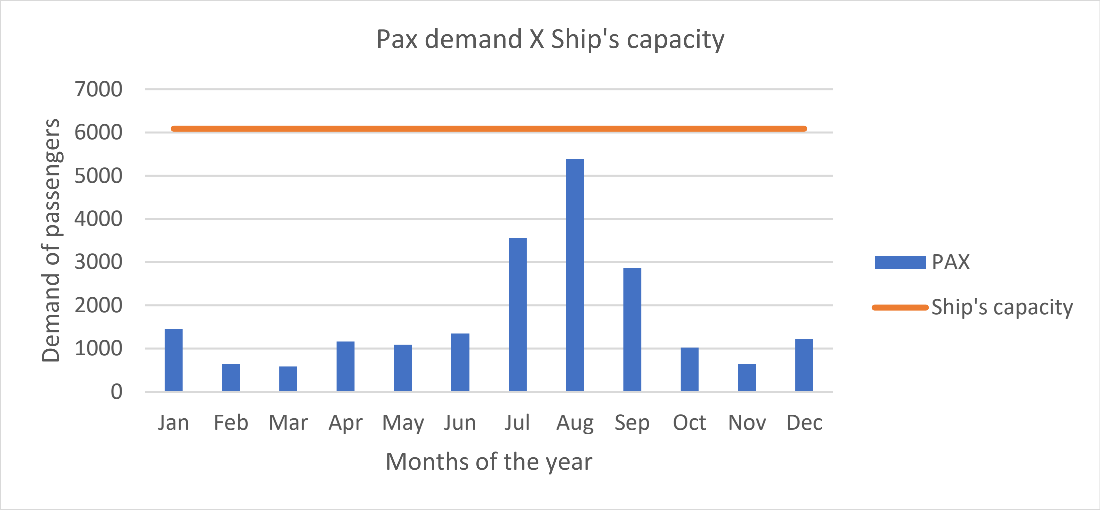


Figure 44 - Second scenario demand versus the ship's capacity for passengers [61]

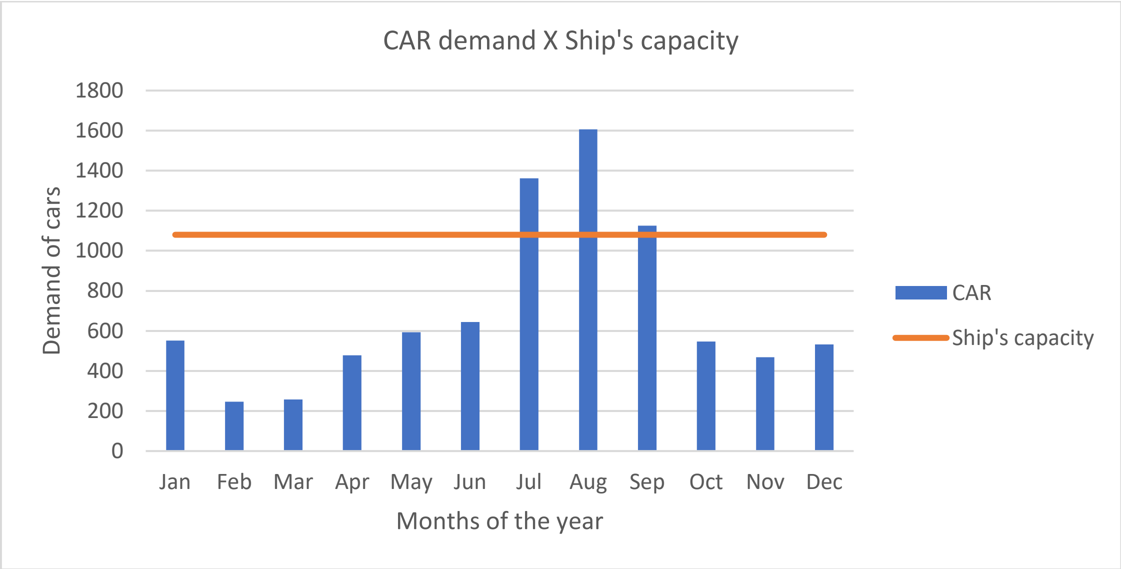


Figure 45 - Second scenario demand versus the ship's capacity for cars [62]

[61] Source: Project numerical tool, Author's elaboration
[62] Source: Project numerical tool, Author's elaboration

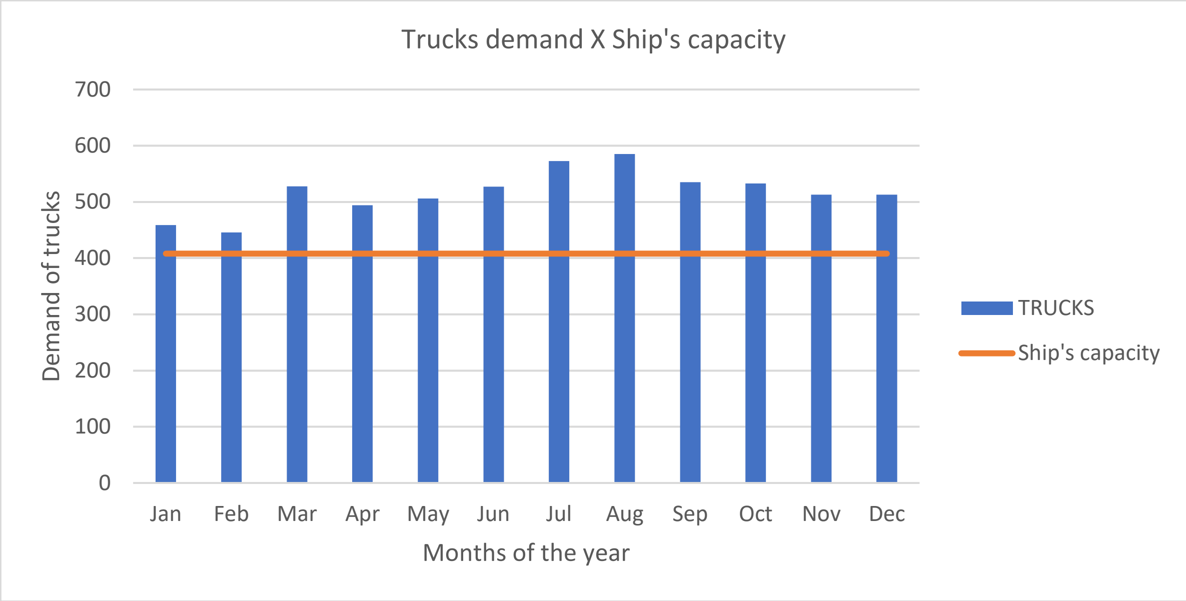


Figure 46 - Second scenario demand versus the ship's capacity for trucks [63]

As done before, the ratio between the maximum global demand and ship's capacity is calculated for cars and trucks, being 67% and 71%, respectively. This scenario will be considering the new building investment for the operator of the route, using the same investment parameters used before, illustrated in Table 17.

Table 17 - Investment parameters for the second scenario [64]

Discount rate	8%
Owner Investment	50%
Guarantees of investment	2%
Interest Rate	1%
Scrap Value [USD]	$20\%\ of\ \$P$
Taxes	20%

After calculating all costs related to the building and operation of the vessel in 20 years of operation, it is possible to plot the global cash flow, presented in Figure 47. As is possible to see the operation has losses and profit depending on the year, considering the initial investment, the total NPV of the operation is negative, with the value exposed below:

$$NPV = \$ \quad (20.364.939) \qquad [USD] \tag{93}$$

[63] Source: Project numerical tool, Author's elaboration
[64] Source: Author's elaboration

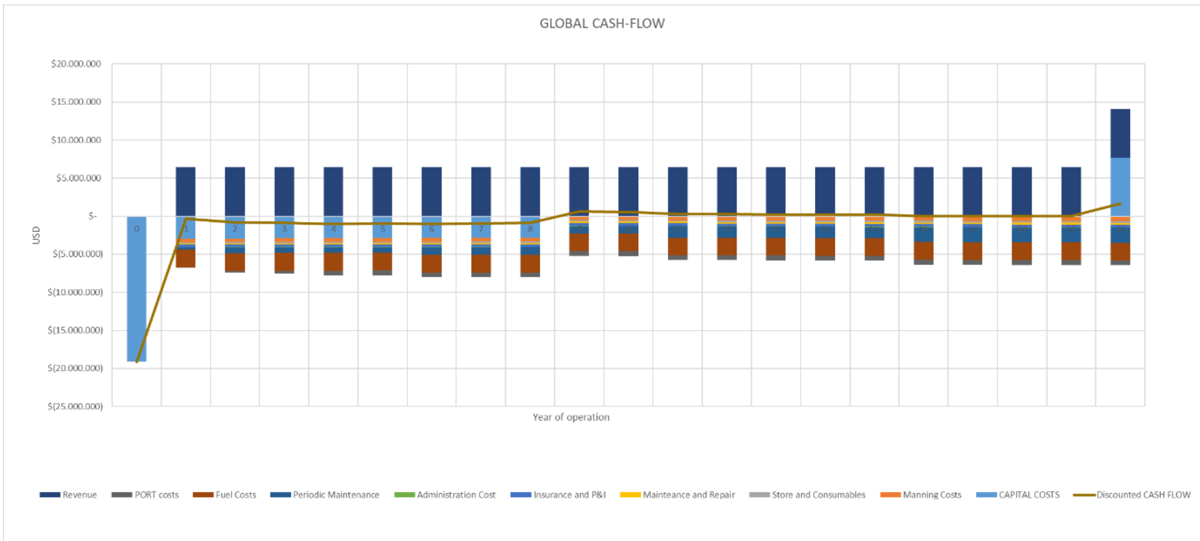


Figure 47 - Global cash flow for the second scenario of the case study [65]

4.3 Discussion and final analysis

In this section, first will be commented on possible reasons for the need for corrections in the numerical model, then the scenarios of the case study will be analyzed, arriving at the main conclusions for the thesis in the next chapter.

Firstly, the numerical model created has reasonable accuracy for the determination of the main particulars for Ro-Pax ships, having average deviations less than 10% for the range of ships sized from 300 lanemeters up to 3000, with different passenger capacity. A problem faced turns out to be the precise sizing of the length of the ship using the lanemeters capacity, once most of the Ro-Pax ships present special equipment for carrying rolling low-weight cargo that is not considered in the numerical tool, meaning a slight increase in the total length due to the lack of this equipment in the model calculations.

A possible solution to avoid this oversizing would be to create an internal cargo distribution for the model, allowing the calculation of the exact required length to carry a certain quantity of trucks and cars. Being a singular solution for each ship sized, turns out to be unnecessary for a general tool like the one created, being acceptable the assumptions made along with the methodology.

The greater divergences are in the predictions of the passenger capacity and both powers, main engine, and auxiliary required powers. For the first parameter, the formula according to Kristensen and Psaraftis (2016), has great accuracy when sizing big lanemeters capacity vessels, but always sub-sizing the passenger's capacity for small vessels, possibly because the ships used by the authors early mentioned are in its majority designed for bigger capacities, most likely missing ships with small lanemeter capacity and large passenger haulage capacity. In this sense, corrections were made in the numerical tool.

[65] Source: Project numerical tool, Author's elaboration

For the predictions of both powers, the calculations are made based on the well-known Holtrop and Menen method. Being a general formula used for all types of ships, individualization of the results must be done through corrections in the results. The divergence can be possibly explained by the format of the hull of the Ro-Pax vessel, having narrower hulls compared to the other product carriers, requiring less power for the main engines. Regarding the auxiliary power, the divergence can be explained most likely for the different possibilities of Genset arrangements and, different types of generators, obscuring the exact prediction of this parameter.

Secondly, in the intention to verify the profitable potential of the route, the numerical tool is used to simulate the real scenario of the operated vessel, being the tool forced to size a $1{,}500$ lanemeters capacity ship to do the financial analysis of the operation, the same capacity operated previously in the route. Remembering that the main idea is to understand if it is more financially efficient to charter a ship (the first scenario) or to build a new vessel to operate it (second scenario).

The first observation to be pointed out is the accuracy of the model with the operated vessel in the route. For the financial analysis, the only relevant divergence was the sub-prediction of the auxiliary power, that when diluted in the global cash flow can be balanced with the higher new building price of the sized vessel.

It is possible to notice that, on the peak demand of the high season, the sized vessel is capable of supplying roundly 62% of the peak of vehicle's demand and all the passengers' demand, even with less passenger's capacity compared with the original vessel. In this context, it is possible to affirm that the original vessel is over-sized for this specific trip, probably because the vessel not only operated this route, but also the one for the Canary Islands, needing more passengers onboard. On the other hand, analyzing the truck's carrying capacity of the operated ship, knowing that it operated two routes in sequence and could not even supply the demand of the first trip, it is possible to say that it was undersized for carrying this type of cargo.

Analyzing the detailed cash flow of the operation of the first scenario, available in APPENDIX 4 – Cash Flow of the case study, it is possible to point out that the annuity, added with the operating and voyage costs, taxes, and the total revenue results, after discounts, arrives into a negative annual cash flow between $1.0\ M\ USD$ and $1.8M\ USD$ depending of the year of operation.

Knowing that passenger's transportation services also include extra onboard revenue for the ship's operator, namely bar/restaurant services, sales of souvenirs, spa and other extras services, that are not considered in this project, because of the lack of information provided by the previous operator of the route, it can be an important variable for the breakeven of the operation. It is known that occasionally in cruise services this type of income can overpasses the sales of passenger tickets, being an important variable for the service financial analysis, and it can be an important development for the methodology for future works. After the financial prediction of the operation, at the end of 20 years of operation, the final balance is negative, with a loss of 27.8 million American dollars.

Having the first scenario analyzed, it is possible to proceed to the second one. As the first comment, the sized newbuilt vessel for this circumstance is slightly bigger than the first one, meaning that the vessel has a greater income, but also, greater operating costs.

Regarding the financial analysis of the operation, available in APPENDIX 4 – Cash Flow of the case study splitting the timeline of the operation, three main periods can be highlighted, first eight years of operation, the following four years, and finally the rest of the operation period.

During the first eight years, by looking more closely at the costs, it is possible to see that the operation only has losses during this period because of the payment of the capital investment. Meaning the operation, particularly operating costs and voyage costs do not exceed the revenue of the vessel. With the subsidies applied in the route and disregarding the capital investment, the operation is lucrative. This in accordance with Baird (2007), Styhre (2009), Douet and Cappuccilli (2011), Baindur, and Viegas (2011) Aperte and Baird (2013), Ng, Sauri, and Turró (2013), and Suárez-Alemán (2016), all of them recognizing that the SSS service operates while it has a financial incentive, and when this one is over, they disappear shortly afterward.

In the following period, it is possible to confirm what was pointed out before, still having some subsidies in the port costs, but this time already paid the bank debt, the operation is lucrative, reaching profit up to almost $600,000\ USD$ after discounts. And as the financial aids finish, the lucrative period of the operation also comes to an end.

Finally, the final period was impacted by the raising of the operating and voyage costs along the 20 years of operation overpassing the revenue income. Probably the most difficult period to evaluate since the freight rate prices respond to market behaviors, and it is assumed the same freight rate for the whole operation. Moreover, the costs, especially the bunker prices can fluctuate and change the final cash flow of the operation.

After the done the analysis, is important to notice that as before, the onboard income is not being considered in the methodology, meaning, the income revenue of the operation can be bigger and possibly sufficient to have a breakeven along with it.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After reviewing evaluations of the feasibility of technical solutions using predefined ships, with a certain size and capacity for different European routes, the need for a study evaluating a sizing solution for a predefined Portuguese route arises. This study meets this urge of a technical study in this important link between the RAM and the Portuguese mainland, resulting in the development of this project.

Using the available information, this thesis allowed the development of a mapping of the behavior of different demands of the route Portimão and Funchal. Drawing a numerical tool that uses this data to size a ship to operate it. In addition, the tool also forecasts the capital and operating costs related to this operation.

The first problem appears before the start of the methodology - in the data source - since little technical information can be found about the route. After getting in contact with entities related to the operation, limited additional data was revealed to develop a better numerical tool, turns out to be necessary to undertake the study over several market behavior assumptions to try to create sufficient information to develop the project, leading to the need to appeal to similar route's data to create the necessary market behavior background.

In a general appraisal, it is possible to see a potential in the market for the creation of the link by ferry, not practicing exaggeratedly high prices of freight rates and having with the operation itself, profit. The main problem, for this to happen, becomes the investment regarding the vessel to operate the route.

The seasonality and governmental incentives are essential to this route to be operated; the ship's operator income depends mostly on these two aspects. On one hand, the seasonality, already known by the previous players of the market, turns out to be a fundamental variable when sizing a vessel to operate the route, considering the summertime the demands are more double than the rest of the year. On the other hand, the reductions of port tariffs are an important aspect of the operation breakeven, knowing the high costs related to this type of operation.

Another important observation must be done, during the sizing process of the required ship in the methodology, some of the equations used, are obtained in studies for general cargo vessels, and perhaps cannot represent a Ro-Pax ship. Thus, a lack of specific design studies for this type of vessel was identified, and an improvement for the design calculations of the methodology is needed niching the formulae used.

In the case study, two different scenarios are evaluated. The first one having the numerical tool simulating the operated ship on the route under a long-time chartering contract, and the second simulating the construction of another ship under the same circumstances.

First noticing that the operated ship was evidently designed to carry passengers on the route, but without cargo capacity, jeopardizing the main revenue of a Ro-Pax ship. Coming to this conclusion comparing the vessels sized in both cases of study with the operated one, since both are under the same circumstances the ship previously operated.

More than this, in the first scenario, it is possible to notice that the service generates losses for the operator, but without information on the onboard revenue of the operated vessel, it becomes difficult to affirm whether or not the route makes a profit at the end of its operation.

For the second scenario, under the prior circumstances, it is sized a vessel with more haulage capacity than the operated vessel. But even with more revenue potential, the vessel has greater costs and when evaluating the total operating cash flow with the new building investment, it is possible to see a great loss for the operator in the end. Important to notice that, for some years the operation has positive balances, but as the subsidies diminish, also does the profit. Leading to two conclusions: the first is that the route is feasible regarding only operating and voyage costs; the second is that, as noticed for other European routes, there is an urge for direct subsidies during the whole period of operation.

After comparing both cases of study, it also becomes evident that the best choice, in financial terms, is to build a vessel to operate the route, once it was the scenario that resulted in less financial loss. Since the demand for the route is very sensitive to the phenomenon of seasonality, becomes evident that the most important aspect is to operate it trying to obtain the minimum loss of revenue potential.

Finally, the results of the project are satisfying, namely, the development of the numerical tool that may be used in the future in studies of the feasibility of the Madeira-Mainland route. During this development knowledge of different naval architecture and maritime areas is used, even including law reviews in the process. All methodology’s calculations respect the different requirements of the operation of the route. And this thesis demonstrates how this methodology may be used to obtain results that may assist shipping companies, ports, and national authorities in the development and promotion of this important national link.

5.2 Recommendations

As this thesis was the first approach to the concept and implementation of a technical study of the feasibility of this particular Portuguese route, it is easy to identify now suitable improvements in the numerical tool for the future.

On a general note, more specific sizing/dimensioning studies for Ro-Pax ships must be done. In this case, the extension of the already existing technical specifications papers for this specific ship type, trying to narrow the regressions created to illustrate real-life situations with more accuracy, especially regarding high-density cargo vessels, that are more and more used for SSS routes, especially regarding the prediction of the auxiliary power.

More accurate results in the sizing of the required ship mean less error in the newbuilding investment of the numerical tool, correcting the costs and making closer to the reality the total cash flow of the operation. Therefore, it is recommended that the results of this thesis are used qualitatively.

More than this, it is important to improve the methodology with the onboard sales information, trying to simulate efficiently the income and costs of a Ro-Pax vessel while operating the service. With more reliable information regarding the cash flow, more trustworthy conclusions can be made using the methodology.

Besides that, another good improvement to the model would be to take into consideration the addition of the special equipment specific for Ro-Pax vessels, namely internal car decks, that rises the haulage capacity of the vessel sized without the need for enlarging the main dimensions of the ship and may affect directly the revenue of this type of operation.

Finally, the next step would be the implementation of the Solver in the tool, to optimize the sizing parameters of the ship for the voyage inputs provided, so in this way, the ship generates the optimal revenue based on the mapped demand of the trip.

REFERENCES

Aperte, X. G., and A. J. Baird. (2013). *Motorways of the Sea Policy in Europe*. Maritime Policy & Management 40(1): 10–26. doi:10.1080/03088839.2012.705028.

APRAM – Portos da Madeira (2011 – 2020), *Movimento Anual de navios e passageiros,* published annually by Portos da Madeira (APRAM)

APRAM (2013 – 2018), *Movimento Anual Carga,* published annually by Portos da Madeira (APRAM)

Autónoma da Madeira (2011), Funchal, Direcção Regional de Estatística

Autonomous Region of Madeira Regional Government (2018), *Concurso Público Internacional para Concessão de Serviços Públicos de Transporte Marítimo de Passageiros e Veículos através de navio ferry entre a Madeira e o Continente Português,* Programa do Concurso

Baindur, D., and J. Viegas. (2011), *Challenges to Implementing Motorways of the Sea Concept—Lessons from the Past.* Maritime Policy & Management 38(7): 673–690. doi:10.1080/03088839.2011.625990.

Baird, A. (2007). *The Economics of Motorways of the Seas*. Maritime Policy and Management 34 (4): 287–310. doi:10.1080/03088830701538976.

Baños, J. F., L. Valdés, E. del Valle, and E. Zapico. (2016). *Economic Importance of the Motorways of the Sea for Tourism: The Experience of the Route Nantes–Gijón*. Maritime Economics & Logistics 1–21. doi:10.1057/ s41278-016-0003-2.

Carreyette, J (1977) *Preliminary ship cost estimation,* Trans. RINA p. 235-258

Cudina & al. (2010), *Multiattribute Decision Making Methodology in the Concept Design of Tankers and Bulk-Carriers*, 11th Symposium on Practical Design of Ships and Other Floating Structures, PRADS. 1, 19-43

Đ. Dundara, O. Kuzmanović, etc. (2010). *New Innovative Design of Ro-Pax Ship,* FAMENA Repository (2.28) p. 374-385

d'Almeida, J. (2009), Arquitectura Naval - *O Dimensionamento do Navio*., Lisboa: Prime Books. (in Portuguese)

Diário da República Eletrónico DRE (2015), *Decreto-Lei n.º 134/2015 de 24 de Julho*

Direcção Regional de Estatística da Madeira, (2012), *Anuário Estatístico da Região*

Douet, M and Cappuccilli, J. F. (2011), *A review of Short Sea Shipping policy in the European Union,* Journal of Transport Geography 19(4):968-976 DOI: 10.1016/j.jtrangeo.2011.03.001

Duarte, E. G. (2010). *Estudo de caso Naviera Armas ED Consulting*. IPDT – Turismo e Consultoria, Porto, Portugal

Duarte, E. G., (2010), *Estudo de Caso – Naviera Armas*, Funchal, Universidade da Madeira

EFTA (2007), *“EFTA Guide to EU Programmes (2007-13)”,* EFTA Bulletin 2

European Comission (2011), *WHITE PAPER Roadmap to a Single Transportation Area – Towards a competitive and resource efficient transport system*, Brussels

European Commission (2011), *Potential of modal shift to rail transport,* Brussels: Community of European Railways

Freitas, J.C. (2015) *LIGAÇÕES MARITIMAS REGULARES - FUNCHAL / PORTIMÃO / TENERIFE Insustentabilidade de uma linha Marítima ou Pura Estratégia de Negócio? ESTUDO DE CASO: NAVIERA ARMAS*, Dissertação de Mestrado, UAL – Universidade Autónoma de Lisboa, Lisboa, Portugal.

Galati & al. (2016). *Competitiveness of Short Sea Shipping: The Case of Olive Oil Industry.* British Food Journal 118(8):1914 – 1929 DOI: 10.1108/BFJ-05-2016-0193

Gerr, David (2001), *Propeller Handbook: The Complete Reference for Choosing, Installing and Understanding Boat Propellers*, International Marine.

Giernalczyk & al (2010). *Estimation Method of Ship Main Propulsion Power, Onboard Power Station Electric Power and Boilers Capacity by Means of Statistics*, Journal of Polish CIMAC, Vol.5, No.1. 33-42

Hijos de J. Barreras, *Hull 1654 VOLCAN DE TIJARAFE,* Vigo, Spain

Holtrop, J. (1984), *A Statistical Re-analysis of Resistance and Propulsion Data*, International Shipbuilding Progress, ISP, Volume 31, Number 363

Holtrop, J. and Mennen, G.G.J. (1977), *A Statistical Power Prediction Method*, International Shipbuilding Progress, Volume 25, p. 253-256

Holtrop, J. and Mennen, G.G.J. (1982), *An Approximate Power Prediction Method,* International Shipbuilding Progress, ISP, Volume 29, Nr 335, 1982

Instituto Nacional de Estatística (2012), *Censos 2011 Resultados Definitivos*, Lisboa, Instituto Nacional de Estatística, I.P.

Instituto Nacional de Estatística (2012), *Estatísticas dos Transportes 2011*, Lisboa, Instituto Nacional de Estatística, I.P.

Kristensen H. O (2015): *Prediction of resistance and propulsion power of Ro-Ro ships.* Report No. 01 of project No. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe.

Kristensen H. O and Psaraftis, H. (2016): *Analysis of technical data of Ro-Ro ships*. Report. The Technical University of Denmark, Copenhagen, Denmark.

Lisbon Port Authority (2013). *Tariff Regulations*. Lisbon, Portugal.

Lupi, M., A. Farina, D. Orsi, and A. Pratelli. (2017). *The Capability of Motorways of the Sea of Being Competitive against Road Transport. The Case of the Italian Mainland and Sicily.* Journal of Transport Geography Maritime Economics and Logistics, Elsevier, vol. 58(C), pages 9-21.

Martínez-López, A., A. Munín-Doce, and L. García-Alonso. (2015) *A Multi-Criteria Decision Method for the Analysis of the Motorways of the Sea: The Application to the Case of France and Spain on the Atlantic Coast*. International Journal of Shipping and Transport Logistics 7(1): 89–113.

Martínez-López, A., J. Kronbak, and L. Jiang. (2013) *Cost and Time Models for Road Haulage and Intermodal Transport Using Short Sea Shipping in the North Sea Region*. Proceedings of IAME 2013 Conference, July 3-5, Marseille, France.

NAVITASHIP (2010). *RoRo & RoPax Market - Challenges and Opportunities.*

Ng, A.K.Y, S. Sauri, and M. Turró. (2013) *Short Sea Shipping In Europe: Issues, Policies And Challenges*. In Finger, M. and Holvad, T. (Eds.): Regulating Transport In Europe 196–217. Cheltenham: Edward Elgar Publishing, Edward Elgar, Cheltenham, Chapter 8, pp. 196-217.

Papadopoulos, F. (2019). *Parametric Design And Optimization Of Large Ro-Pax Ferry,* Diploma Thesis, National Technical University Of Athens School Of Naval Architecture And Marine Engineering Division Of Ship Design And Maritime Transport, Athens, Greece.

Quintal, Hugo M. D. (2013). *Exploração das ligações via ferryboat entre o continente e as ilhas: Estudo de viabilidade do serviço de transporte.* Dissertação de Mestrado, ISG - Instituto Superior de Gestão, Lisboa, Portugal.

Sambracos, E., and M. Maniati. (2012). *Competitiveness between Short Sea Shipping and Road Freight Transport in Mainland Port Connections; the Case of Two Greek Ports.*" Maritime Policy and Management , 39:3, 321-337, DOI: 10.1080/03088839.2012.671545

Santos, T.A. & Guedes Soares, C. (2016), *Modelling of Transportation Demand in Short Sea Shipping.* Instituto Superior Técnico, Lisbon, Portugal. Maritime Economics & Logistics 19(4) DOI: 10.1057/mel.2016.9

Santos, T.A. (2015*). Economics of Ship Operations*. Macmillan Publishers Ltd. 1479-2931 Maritime Economics & Logistics 1–28

Sauri, S. (2006). *Cost Structure in a Short Sea Shipping Line.* Journal of Maritime Research III(2): 53–66.

Schneekluth, H.and Bertram, V. (1998), *Ship design for efficiency and economy*, Butterworth+Heinemann, Oxford, Boston : Butterworth-Heinemann, 1998.

Significant Ships (1990 – 2018), published annually by Royal Institution of Naval Architects (RINA)

Sines, Administração do Porto de, (2012), *Regulamento de Tarifas da APS, SA 2013*, Sines, Administração do Porto de Sines

SRETC – APRAM (2016), *CONSULTA PARA A LIGAÇÃO MARÍTIMA DE PASSAGEIROS E CARGA RODADA ENTRE A MADEIRA E O CONTINENTE, Relatório*

Stopford, M. (2009). *Maritime economics*. Blucher Verlag, Berlin, Germany.

Styhre, L. (2009). *Strategies for Capacity Utilization in Short Sea Shipping*. Maritime Economics & Logistics, 11, p. 418–437.

Suárez-Alemán, A. (2016*). Short Sea Shipping in Today's Europe: A Critical Review of Maritime Transport Policy.* Maritime Economics & Logistics, 18(3) DOI: 10.1057/mel.2015.10

Suárez-Alemán, A., J. Campos, and J. L. Jiménez. (2015). *The Economic Competitiveness of Short Sea Shipping: An Empirical Assessment for Spanish Ports.* International Journal of Shipping and Transport Logistics 7 (1), 42-67.

Tiago A. Santos & C. Guedes Soares (2017), *Methodology for ro-ro ship and fleet sizing with application to short sea shipping*, Maritime Policy & Management, 44:7, 859-881, DOI: 10.1080/03088839.2017.1349349

Trant, G., and K. Riordan. (2009). *Feasibility of New RoRo / Ropax Services between Ireland and Continental Europe*. SKEMA project Technical Report, 208,718 173,095.

Tsamboulas, D., (2008), *Development Strategies for Intermodal Transport in Europe*, Chapters, in: Rob Konings & Hugo Priemus & Peter Nijkamp (ed.),The Future of Intermodal Freight Transport, chapter 14, Edward Elgar Publishing.

Tsamboulas, D., A. Lekka, and A. Rentziou. (2015). *Development of Motorways of the Sea in the Adriatic Region*. Maritime Policy & Management 42(7):653-668 DOI: 10.1080/03088839.2015.1078509

Tzannatos, E. Papadimitriou, S., & Katsouli, A. (2014) *The cost of modal shift: A short sea shipping service compared to its alternative in Greece.* European Transport \ Transporti Europei 1(56): 1–20.

Ventura, M. (2016), *Estimation Methods for Naval Architecture*, Instituto Superior Técnico, Lisbon, Portugal.

Wijnolst N. & Wergeland T. (2009), *Shipping Innovation,* Published by IOS Press BV under the imprint Delft University Press, Amsterdam, The Netherlands

WEBSITES

1. Adiministração dos Portos de Sines e do Algarve, S.A. - http://www.apsinesalgarve.pt/
2. CruiseMapper - Volcan de Tijarafe ferry - https://www.cruisemapper.com/ships/Volcan-de-Tijarafe-ferry-1265
3. Descubra a Madeira - http://www.visitmadeira.pt/pt-pt/a-madeira
4. DREM – Direção Regional de Estatistica da Madeira - https://estatistica.madeira.gov.pt/
5. Google Earth - https://earth.google.com/web/
6. Google Maps - https://www.google.com/maps/

7. Greencarrier Freight Services - https://freightservices.greencarrier.com/short-sea-shipping-great-alternative-road-freight/
8. Intermodal Promotion Centre Portugal - https://www.shortsea.pt/sobre-nos/o-que-e-o-short-sea/
9. Marine Insight - What are Ro-Ro ships? https://www.marineinsight.com/types-of-ships/what-are-ro-ro-ships/
10. Port of Leixões APDL - https://www.apdl.pt/en_US/web/apdl/header
11. Port.com - http://ports.com/sea-route/
12. Porto de Lisboa Atlantic meeting point - http://www.portodelisboa.pt/portal/page/portal/PORTAL_PORTO_LISBOA
13. Porto de Setúbal - http://www.portodesetubal.pt/index.htm
14. Portos da Madeira - http://www.apram.pt/site/index.php/pt/
15. ResearchGate - *Uncertainty in design and operational parameters: Application of Real Options for valuation of ship design alternatives.* https://www.researchgate.net/figure/Average-number-of-passengers-on-Ro-Pax-vessels-source-ShipPax-NAVITASHIP_fig23_279447378
16. Ship&Bunker – Rotterdam Bunker Prices - https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam
17. Slide Share, - Estudo De Caso Naviera Armas ED Consulting. - https://pt.slideshare.net/egomesduarte/estudo-de-caso-naviera-armas-eduardo-duarte-4810965
18. The Engineering ToolBox – Liquids density - https://www.engineeringtoolbox.com/liquids-densities-d_743.html
19. The Geography of Transportation System - https://transportgeography.org/?page_id=2258

APPENDIX 1 – RO-RO SHIP DATABASE

In this Appendix, the database created in the project will be exposed, but only the identification of the ships. In total there are 107 ships identified. In which, several different types of Ro-Ro and Ro-Pax are available.

IDENTIFICATION				DESIGN
IMO	**Name**	**Flag**	**Year**	**LOA [m]**
9214991	Ulysses	Cyprus	2001	209.80
8915641	Sirimau	Indonesia	1991	99.80
9051284	Calendonian Isles	UK	1993	94.28
9370458	Malaspina Sky	Canada	2008	102.40
9112466	MN Toucan	France	1995	115.00
9031997	Las Palmas de Gran Canaria	Spain	1993	116.80
968330	Berkarar	Turkmenistan	2014	155.80
9631797	Messina	Italy	2013	147.00
9021485	Zadar	Morroco	1993	116.00
9143491	Fior de Levante	Greece	1998	114.50
9158953	Clansman	UK	1998	99.00
9211975	Hebrides	UK	2001	99.40
9665437	Loch Seaforth	UK	2014	117.90
9383390	Zhong Tie Bo Hai 1 Hao	China	2006	182.60
9170705	Ben-my-Chree	Isle of Man	1998	125.20
9201750	Commodore Clipper	Bahamas	1999	129.40
9408413	Northern Expedition	Canada	2009	151.78
9687306	Mobile Express	Italy	2014	178.80
9174828	Aratere	New Zealand	1998	150.00
8917388	Stena Challenger	UK	1991	154.00
9079999	Amman	Egypt	1995	139.70
9110781	BANG CHUI DAO	China	1995	134.80
9107772	Nordkapp	Norway	1996	123.30
9004592	Mutiara Persada III	Japan	1991	151.13
9608348	Ferry Naminoue	Japan	2012	145.00
9039391	Juan J Sister	Spain	1993	151.10
9087477	Robin Hood	Germany	1995	179.60
9669861	F.A.GAUTHIER	Canada	2014	133.20
9597616	Silver Princess	Japan	2012	150.00
9015668	Spirit of British Columbia	Canada	1993	167.50
9108350	Polonia	Bahamas	1995	169.90
9267390	Lobo Marinho	Portugal	2003	112.00
9332755	COASTAL RENAISSANCE	Canada	2007	160.00
9203916	Fundy Rose	Canada	2000	123.80
9281322	Vólcan de Tamasite	Spain	2004	142.50
9390367	Martin I Soler	Spain	2008	165.30
9376347	Sunflower Pearl	Japan	2008	165.50

9210115	King Tamatoa	France	2000	134.00
9320128	CÔTE D'ALBÂTRE:	France	2006	142.45
9212151	Lisco Gloria	Lithuania	2001	199.40
9006629	Ocean	Japan	1991	192.91
9050618	Kalliste	France	1993	165.00
9050826	Paglia Orba	France	1994	165.80
9364978	Stena Baltica	UK	2007	168.00
8908466	M / S PRINCE FILIP	Belgium	1991	163.40
9007283	European Seaway	UK	1991	179.00
9015254	Pride of Burgundy	UK	1993	179.40
9469376	Stena Transporter	The Netherlands	2011	212.00
9244958	Hjaltland	UK	2002	125.00
9227390	Norrona	Faroe Islands	2003	165.74
9238337	Mont St Michel	France	2002	173.95
8922163	Asterion II	Japan	1991	192.50
9107942	Kaitaki	New Zealand	1995	181.60
9015735	Majestic	Italy	1993	188.22
9137997	Rosalind Franklin	Cyprus	1999	188.30
9237242	Cracovia	Bahamas	2002	180.00
9147291	Kaiarahi	New Zealand	1998	180.00
9364980	Armonique	France	2008	168.00
9125891	Pegasus One	Belize	1996	94.50
9056583	Norbank	The Netherlands	1993	166.75
9265419	Tassili II	Algeria	2004	145.00
9263370	Ciudad de Ibiza	Spain	2003	160.00
9288605	Hamanasu	Japan	2004	224.82
9586605	STAVANGER FJORD	Denmark	2013	170.00
9125944	Stena Line	Sweden	1996	184.35
9235529	Stena Adventurer	UK	2002	210.80
9144275	Aries	Togo	1998	145.00
9241542	San Rancisco de Asis	Venezuela	2001	115.25
9217125	Ciudad de Granada	Spain	2001	172.00
6605058	Moby Dick	Italy	1998	200.00
9606900	Viking Grace	Finland	2013	218.50
9217230	Nils Holgersson	Germany	2001	190.75
9524231	Spirit of Britain	Cyprus	2011	213.00
9088859	Girolata	France	1995	177.30
9278234	Color Fantasy	Norway	2004	223.70
9208394	European Causeway	Bahamas	2000	159.50
9086588	Skania	Bahamas	1995	173.70
9328912	Alakai	USA	2007	106.00
9294238	NATCHAN RERA	Taiwan	2007	112.60
9557848	Betancuria Express	Spain	2011	112.60
9328015	HSC Gotlandia II	Sweden	2006	122.00
9247510	Pascal Paoli	France	2003	175.00
9230476	Danielle Casanova	France	2002	176.00

9208617	Pride of Rotterdam	The Netherlands	2001	215.00
9526332	Piana	France	2011	180.00
9374519	Color Superspeed I	Norway	2008	212.75
9232527	Côte des Dunes	France	2001	185.00
9215505	Stena Nordica	Bahamas	2001	169.80
9375654	Viking XPRS	Estonia	2008	186.71
9319442	Finnstar	Finland	2006	218.80
9158434	Spirit of Tasmania	Australia	1998	194.30
9268708	Pont-Aven	France	2004	184.30
9197105	Blue Star 1	Greece	2000	176.10
9203174	Mega Express	Italy	2001	176.01
9364722	Star	Estonia	2007	186.00
9216028	Olympic Chanpion	Greece	2000	204.10
9208071	Zeus Palace	Italy	2001	212.00
9222522	Bithia	Italy	2001	214.00
9293404	Nuraghes	Italy	2004	214.00
9351476	Cruise Roma	Italy	2008	225.00
9598579	Tanit	Tunisia	2012	210.00
9080194	One World Karadeniz	Liberia	1996	125.00
9214276	La Superba	Italy	2002	211.50
9220330	Cruise Bonaria	Italy	2001	214.00
9204063	Knossos Palace	Greece	2000	214.00
9116266	Hakuou	Japan	1996	199.45

IMO Number	Ship Name	Flag	Year	Loa [m]
9144744	Raffaelle Rubattino	Italy	2000	180.30
9244958	Hjaltland	United Kingdom	2002	125.00
9232527	Cote Des Dounes	France	2001	185.00
9237589	Romantika	Latvia	2002	192.90
9223784	Visby	Sweden	2003	195.00
9214379	Finland	Finland	2001	174.99
9222522	Bithia	Italy	2001	214.00
9216028	Olympic Champion	Greece	2000	204.00
9238337	Mont Saint Michel	France	2002	173.95
9227417	Superfast Xi	Greece	2002	199.90
9198941	Superfast Vii	United Kingdom	2001	203.40
9198939	Cruise Olbia	Italy	2001	203.90
9220330	Cruise Bonaria	Italy	2001	214.00
9208071	Zeus Palace	Italy	2001	212.00
9135262	Ariadne	Greece	1996	199.95
9208629	Pride Of Hull	Bahamas	2001	215.51
9208394	European Causeway	Bahamas	2000	156.20

9230476	Danielle Casanova	France	2002	175.00
9217230	Nils Holgersson	Germany	2001	190.75
9267390	Lobo Marinho	Portugal	2003	112.00
9170705	Ben My Chree	United Kingdom	1998	125.20
9281281	Victoria I	Estonia	2004	192.90
9278234	Color Fantasy	Norway	2004	223.75
9203174	Mega Express	Italy	2001	172.70
9214991	Ulysses	Cyprus	2001	209.80
9214276	La Superba	Italy	2002	211.50
9143441	Excellent	Italy	1998	203.00
9217125	Sorolla	Spain	2001	172.00
9211975	Hebrides	United Kingdom	2001	99.40
9227390	Norrona	Faroe Islands	2003	165.74
9241786	Blue Star Naxos	Greece	2002	124.20
9209063	Lochnevis	United Kingdom	2000	49.20
9506289	Volcan De Teide	Spain	2010	175.00
9348558	Volca De Taburiente	Spain	2006	130.45
9081590	(Ex-Volcan De Tauce) Sinaa	Jordan	1995	120.00
9398890	Volcan De Tijarafe - Tamadaba	Spain	2008	154.51
9281334	Volcan De Timanfaya	Spain	2005	142.45
9506291	Volcan Tinamar	Spain	2011	175.00
9268411	Volcan Tindaya	Spain	2003	78.10
9606900	Viking Grace	Finland	2013	218.60
9809679	Wb Yeats	Cyprus	2018	194.80
9773064	Megastar	Estonia	2017	212.00
N/A	Hypatia De Alejandria		2019	186.50
9665437	Loch Seaforth	UK	2014	117.90
9158953	Clansman	UK	1998	99.00
9794513	Glen Sannox	United Kingdom	2018	102.40
9408413	Northen Expedition	Canada	2009	151.78
N/A	San Sha 1 Hao	China	2014	123.00
9736901	Veteran	Canada	2015	81.05
9434060	Spitsbergen	Norway	2015	100.54
9214288	La Suprema	Italy	2003	211.50
9184419	Excelsior	Italy	1998	202.78
9100267	Fantastic	Italy	1996	188.22
9351488	Cruise Barcelona	Italy	2008	225.00
9349863	Color Magic	Norway	2007	223.75
7907673	El. Venizelos	Greece	1992	175.40
9104835	Rhapsody	Italy	1996	172.00
9420423	Étretat	France	2008	186.46
8916607	Kydon	Greece	1991	192.00
9216030	Hellenic Spirit	Greece	2001	204.00

8020927	Prevelis	Greece	1980	142.50
9349760	Connemara	Cyprus	2007	186.50
7814046	Kriti I	Greece	1979	191.80
7814058	Kriti Ii	Greece	1979	191.80
8703232	Tom Sawyer	Germany	1989	177.04
6921282	Al Salam Boccaccio 98	Panama	1970 (refit 1991)	131.00
9587855	Berlin	Germany	2016	169.00
9350680	Athena Seaways	Lithuania	2007	199.00
9320128	Côte D'albatre	France	2004	142.45
9305843	Côte Des Flandres	France	2005	186.00
9293088	Delft Seaways	United Kingdom	2006	186.00
9288605	Hamanasu	Japan	2004	224.82
9293404	Nuraghes	Italy	2004	214.00
9265419	Tassili Ii	Algeria	2004	142.50
8517736	Pride Of Dover	Sierra Leone	1987	169.40
8501957	Pride Of York	Bahamas	1987	179.41
8701674	Pearl Seaways	Denmark	1989	178.40
8712520	Gnv Atlas	Italy	1990	161.25
8715259	Silja Serenade	Finland	1990	203.00
8908466	Calais Seaways	France	1991	163.61
9006629	Ocean	St Kitts and Nevis	1991	192.91
8911516	Monte D'oro	France	1992	145.00
9007130	Barfleur	France	1992	157.65
8917601	Gabriella	Finland	1992	169.40
9006253	Normandie	France	1992	161.45
9035096	Baja Star	Italy	1992	170.00
9021485	Zadar	Croatia	1993	116.00
9031997	Las Palmas De Gran Canaria	Spain	1993	116.80
9035876	Blue Galaxy	Greece	1992	192.00
9086588	Skania	Bahamas	1995	173.70
9088859	Girolata	France	1995	177.30
9110781	Bang Chui Dao	China	1995	134.80
9107942	Kaitiki	New Zealand	1995	181.60
9087477	Robin Wood	Germany	1995	179.71
9112765	Kattegat	Cyprus	1996	136.40
9606895	Suzuran	Japan	1996	199.45
9147306	Aquarius Brazil	Portugal	1999	179.95
9145205	Kennicott	United States of America	1998	116.41
9158434	Spirit Of Tasmania Ii	Australia	1998	194.3
9143491	Fior Di Levante	Greece	1998	114.5
9201750	Commodore Clipper	Bahamas	1999	129.4
9137997	Finnclipper	Cyprus	1999	188.3

9197105	Blue Star 1	Greece	2000	176.1
9203916	Fundy Rose	Canada	2000	123.8
9204063	Knossos Palace	Greece	2000	214
9215505	Stena Nordica	United Kingdom	2001	169.8
9212151	Lisco Gloria	Lithuania	2001	199.4
9208617	Pride Of Rotterdam	Netherlands	2001	215
9237242	Cracovia	Bahamas	2002	180
9235517	Stena Scandinavia	Sweden	2002	210.8
9247510	Pascal Paoli	France	2003	175
9268708	Pont-Aven	France	2004	184.3
9281322	Volcan Tamasite	Spain	2004	142.45
9323699	Hammerodde	Denmark	2005	124.9
9293076	Dunkerque Seaways	United Kingdom	2005	186.6
9299393	Moby Aki	Italy	2005	175
9305154	Pu Tuo Dao	China	2005	137.3
9275218	Smyrill	Faroe Islands	2005	138
9320128	Cote D'albatre	France	2006	142.45
9319442	Finnstar	Finland	2006	218.8
9364722	Star	Estonia	2007	186
9351476	Cruise Roma	Italy	2008	225
9390367	MARTIN I SOLER	Spain	2008	165.3
9376347	Sunflower Pearl	Japan	2008	165.5
9375654	Viking Xprs	Estonia	2008	186.71
9524231	Spirit Of Britain	United Kingdom	2011	213
9608348	Ferry Naminoue	Japan	2012	145
9597616	Silver Princess	Japan	2012	150
9598579	Tanit	Tunisia	2012	210
9586605	Stavangerfjord	Norway	2013	170
9441130	Abel Matutes	Spain	2010	190.5
9498767	Marie Curie	Cyprus	2019	186.5
9565041	Blue Star Patmos	GREECE	2012	145.9
9807293	Stena Estrid	United Kingdom	2019	215.0

APPENDIX 2 – GENERATOR SET SPECIFICATIONS

3516C Generator Set

Electric Power

CAT

Caterpillar is leading the power generation marketplace with Power Solutions engineered to deliver unmatched flexibility, expandability, reliability, and cost-effectiveness.

Specifications

Generator Set Specifications	
Minimum Rating	1650 ekW
Maximum Rating	2500 ekW
Voltage	220 to 13800 volts
Frequency	60 Hz
Speed	1800 RPM

Generator Set Configurations	
Emissions/Fuel Strategy	U.S. EPA Certified for Stationary Emergency Use Only (Tier 2 Nonroad Equivalent Emission Standards), Low Fuel Consumption

Engine Specifications		
Engine Model	3516C, ATAAC, V-16,4-Stroke Water-Cooled Diesel	
Bore	170 mm	6.69 in
Stroke (Std)	190 mm	7.48 in
Stroke (HD)	215 mm	8.46 in
Compression Ratio	14.7:1	
Aspiration	TA	
Governor Type	Adem™3	
Fuel System	Electronic unit injection	

ELECTRIC POWER - Technical Spec Sheet
STANDARD

3516C

2500 ekW/ 3125 kVA/ 60 Hz/ 1800 rpm/ 480 V/ 0.8 Power Factor

CAT

Rating Type: STANDBY

Emissions: U.S. EPA Stationary Emergency Use Only

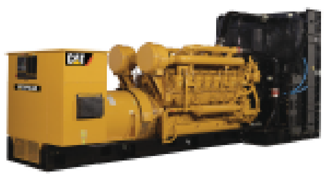


Image shown may not reflect actual configuration

3516C

2500 ekW/ 3125 kVA
60 Hz/ 1800 rpm/ 480 V

	Metric	English
Package Performance		
Genset Power Rating with Fan @ 0.8 Power Factor	2500 ekW	
Genset Power Rating	3125 kVA	
Aftercooler (Separate Circuit)	N/A	N/A
Fuel Consumption		
100% Load with Fan	656.8 L/hr	173.5 gal/hr
75% Load with Fan	510.8 L/hr	134.9 gal/hr
50% Load with Fan	372.4 L/hr	98.4 gal/hr
25% Load with Fan	219.3 L/hr	57.9 gal/hr
Cooling System*		
Engine Coolant Capacity	233.0 L	61.6 gal
Inlet Air		
Combustion Air Inlet Flow Rate	204.2 m³/min	7212.2 cfm
Max. Allowable Combustion Air Inlet Temp	50 ° C	122 ° F
Exhaust System		
Exhaust Stack Gas Temperature	490.7 ° C	915.2 ° F
Exhaust Gas Flow Rate	554.5 m³/min	19578.8 cfm
Exhaust System Backpressure (Maximum Allowable)	6.7 kPa	27.0 in. water

APPENDIX 3 – ORIGINAL DOCUMENT

Viagens sem acomodação: 50% do preço total do bilhete
Viagens com acomodação: 40% do preço total do bilhete
Viagens sem acomodação+viatura: 40% do preço total do bilhete
Viagens com acomodação+viatura: 30% do preço total do bilhete

O cálculo é feito, em todos os casos, sobre o preço total do bilhete por passageiro, até um limite de 400,00 €, para viagens de ida e volta, ou 200,00 €, no caso de viagens one-way. Quando o preço total, por passageiro, exceder este limite, o remanescente será suportado pelo próprio.

Figure 48 - Governmental subsidy for residences [66]

No seguimento do processo em epigrafe, e em resposta à Vossa solicitação, a APS poderá atribuir um incentivo à operação, através da redução extraordinária das suas tarifas portuárias, incluindo a Tup/navio, Tarifa de Pilotagem, Tarifa de Amarração e a Tarifa de Tráfego de Passageiros, de forma progressiva, por cada ano de operação:

- 1º ano: redução de 87,5% sobre as taxas indicadas;
- 2º ano: redução de 75% sobre as taxas indicadas;
- 3º ano: redução de 50% sobre as taxas indicadas;
- 4º ano e seguintes (até ao 10º ano de operação): redução de 18% sobre as taxas indicadas.
- Nota: as escalas ao Domingo têm um custo adicional de 300,00€.

Caso tenha alguma duvida, por favor disponha!

Com os melhores cumprimentos,

José Pedro Soares
Administrador
Executive Member of the Board

Figure 49 - Extraordinary reduction of the Ports tariffs [67]

[66] Source: Consulta Para A Ligação Marítima De Passageiros E Carga Rodada Entre A Madeira E O Continente
[67] Source: Public emails exchanged by the Executive Member of the Board of the APS, S.A.

1 – Existirá um incentivo à operação, através da redução das taxas portuárias aplicáveis pela APRAM (porto do Funchal ou Caniçal), de forma progressiva, por cada ano de operação. Isto inclui TUP/Navio, TUP/Carga, taxa de pilotagem, taxa por serviços de amarração e desamarração, tarifa de tráfego de passageiros e fornecimentos.

1º Ano: isento do pagamento de todas as taxas

2º Ano: redução de 85% sobre todas as taxas

3º Ano: redução de 70% sobre todas as taxas

4º Ano e seguintes: redução de 50% sobre todas as taxas

2 – Existirá um subsídio de mobilidade, aplicável aos passageiros residentes na Região Autónoma da Madeira, em termos a definir na portaria a publicar para esse efeito, antes do início da operação.

3 – Não existirá qualquer subsídio direto ao operador, nem para o transporte de carga, nem para o transporte de passageiros.

4 – Existirá um envelope financeiro de 80.000 EUR anuais para promoção da operação no mercado português.

5 – Existe um incentivo destinado às empresas da Madeira que financia em 100% o custo de transporte de mercadorias produzidas na Região Autónoma da Madeira, bem como das matérias-primas ali reprocessadas, enquadrado no documento "Funcionamento 2020 - Sistema de apoio à compensação dos custos adicionais das empresas da Região Autónoma da Madeira".

Figure 50 - APRAM subsidy for the line in the first years [68]

[68] Source: Consulta para ligação marítima de passageiros e carga entre a Madeira e o Continente

APPENDIX 4 – CASH FLOW OF THE CASE STUDY

Initial investment	Installments	Interest	Residual Value	Annuity	OPEX	Fuel Costs	PORT costs	SUM COSTS	Revenue	IDEAL CASH FLOW	Taxes	CASH FLOW AFTER TAXES	Discounted CASH FLOW
-47404654,28													
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (1.418.789)	$ (2.227.951)	$ (65.045)	$ (7.857.996)	$ 6.369.944	$ (1.488.052)	$ -	$ (1.488.052)	$ (1.377.826)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (1.866.678)	$ (2.227.951)	$ (191.951)	$ (8.432.790)	$ 6.369.944	$ (2.062.846)	$ -	$ (2.062.846)	$ (1.768.558)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (1.884.348)	$ (2.227.951)	$ (383.901)	$ (8.642.410)	$ 6.369.944	$ (2.272.466)	$ -	$ (2.272.466)	$ (1.803.957)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (1.902.342)	$ (2.227.951)	$ (632.897)	$ (8.909.400)	$ 6.369.944	$ (2.539.456)	$ -	$ (2.539.456)	$ (1.866.576)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (1.920.667)	$ (2.227.951)	$ (632.897)	$ (8.927.725)	$ 6.369.944	$ (2.557.781)	$ -	$ (2.557.781)	$ (1.740.783)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.176.353)	$ (2.227.951)	$ (632.897)	$ (9.183.411)	$ 6.369.944	$ (2.813.467)	$ -	$ (2.813.467)	$ (1.772.962)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.195.360)	$ (2.227.951)	$ (632.897)	$ (9.202.418)	$ 6.369.944	$ (2.832.474)	$ -	$ (2.832.474)	$ (1.652.722)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.214.718)	$ (2.227.951)	$ (632.897)	$ (9.221.776)	$ 6.369.944	$ (2.851.832)	$ -	$ (2.851.832)	$ (1.540.756)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.234.434)	$ (2.227.951)	$ (632.897)	$ (9.241.492)	$ 6.369.944	$ (2.871.548)	$ -	$ (2.871.548)	$ (1.436.489)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.254.515)	$ (2.227.951)	$ (632.897)	$ (9.261.572)	$ 6.369.944	$ (2.891.628)	$ -	$ (2.891.628)	$ (1.339.383)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.749.013)	$ (2.227.951)	$ (632.897)	$ (9.756.071)	$ 6.369.944	$ (3.386.127)	$ -	$ (3.386.127)	$ (1.452.252)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.769.845)	$ (2.227.951)	$ (632.897)	$ (9.776.903)	$ 6.369.944	$ (3.406.959)	$ -	$ (3.406.959)	$ (1.352.950)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.791.063)	$ (2.227.951)	$ (632.897)	$ (9.798.121)	$ 6.369.944	$ (3.428.177)	$ -	$ (3.428.177)	$ (1.260.534)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.812.675)	$ (2.227.951)	$ (632.897)	$ (9.819.733)	$ 6.369.944	$ (3.449.789)	$ -	$ (3.449.789)	$ (1.174.519)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (2.834.689)	$ (2.227.951)	$ (632.897)	$ (9.841.747)	$ 6.369.944	$ (3.471.803)	$ -	$ (3.471.803)	$ (1.094.457)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (3.331.160)	$ (2.227.951)	$ (632.897)	$ (10.338.217)	$ 6.369.944	$ (3.968.273)	$ -	$ (3.968.273)	$ (1.158.301)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (3.354.001)	$ (2.227.951)	$ (632.897)	$ (10.361.059)	$ 6.369.944	$ (3.991.115)	$ -	$ (3.991.115)	$ (1.078.674)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (3.377.269)	$ (2.227.951)	$ (632.897)	$ (10.384.326)	$ 6.369.944	$ (4.014.382)	$ -	$ (4.014.382)	$ (1.004.595)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (3.400.970)	$ (2.227.951)	$ (632.897)	$ (10.408.028)	$ 6.369.944	$ (4.038.084)	$ -	$ (4.038.084)	$ (935.673)
$ (4.828.269)	$ (5.925.582)	$ (169.997)	$ 414.359	$ (4.146.210)	$ (3.425.115)	$ (2.227.951)	$ (632.897)	$ (10.432.173)	$ 6.369.944	$ (4.062.229)	$ -	$ (4.062.229)	$ (871.544)

Figure 51 - Entire global cash flow for the first scenario of the case of study [69]

[69] Source: Author's Elaboration

Initial price	Scrap price	Installments	Capital in debt	Garantees	Debt Interest	Sum of costs
$ (48.499.297)						$ (19.133.969)
		$ (6.062.412)	$ 48.499.297	$ (969.986)	$ (484.993)	$ (2.965.765)
		$ (6.062.412)	$ 42.436.885	$ (969.986)	$ (424.369)	$ (2.941.848)
		$ (6.062.412)	$ 36.374.473	$ (969.986)	$ (363.745)	$ (2.917.930)
		$ (6.062.412)	$ 30.312.061	$ (969.986)	$ (303.121)	$ (2.894.013)
		$ (6.062.412)	$ 24.249.649	$ (969.986)	$ (242.496)	$ (2.870.095)
		$ (6.062.412)	$ 18.187.236	$ (969.986)	$ (181.872)	$ (2.846.178)
		$ (6.062.412)	$ 12.124.824	$ (969.986)	$ (121.248)	$ (2.822.260)
		$ (6.062.412)	$ 6.062.412	$ (969.986)	$ (60.624)	$ (2.798.343)
			$ (0)			$ -
						$ -
						$ -
						$ -
						$ -
						$ -
						$ -
						$ -
						$ -
						$ -
						$ -
	$ 19.399.719					$ 7.653.588

Figure 52 - Capital Costs for the second scenario of study

Manning Costs	Store and Consumables	Mainteance and Repair	Insurance and P&I	Administration Cost	Periodic Maintenance	Fuel Costs	PORT costs
$ (448.169)	$ (160.202)	$ (166.707)	$ (350.958)	$ (27.616)	$ (287.010)	$ (2.326.039)	$ (65.457)
$ (457.132)	$ (163.406)	$ (170.041)	$ (352.713)	$ (27.893)	$ (727.489)	$ (2.326.039)	$ (193.698)
$ (466.275)	$ (166.674)	$ (173.442)	$ (354.476)	$ (28.172)	$ (727.489)	$ (2.326.039)	$ (387.397)
$ (475.600)	$ (170.008)	$ (176.911)	$ (356.249)	$ (28.453)	$ (727.489)	$ (2.326.039)	$ (638.679)
$ (485.112)	$ (173.408)	$ (180.449)	$ (358.030)	$ (28.738)	$ (727.489)	$ (2.326.039)	$ (638.679)
$ (494.815)	$ (176.876)	$ (184.058)	$ (359.820)	$ (29.025)	$ (969.986)	$ (2.326.039)	$ (638.679)
$ (504.711)	$ (180.414)	$ (187.739)	$ (361.619)	$ (29.315)	$ (969.986)	$ (2.326.039)	$ (638.679)
$ (514.805)	$ (184.022)	$ (191.494)	$ (363.427)	$ (29.609)	$ (969.986)	$ (2.326.039)	$ (638.679)
$ (525.101)	$ (187.702)	$ (195.324)	$ (365.245)	$ (29.905)	$ (969.986)	$ (2.326.039)	$ (638.679)
$ (535.603)	$ (191.456)	$ (199.230)	$ (367.071)	$ (30.204)	$ (969.986)	$ (2.326.039)	$ (638.679)
$ (546.315)	$ (195.286)	$ (203.215)	$ (368.906)	$ (30.506)	$ (1.454.979)	$ (2.326.039)	$ (638.679)
$ (557.242)	$ (199.191)	$ (207.279)	$ (370.751)	$ (30.811)	$ (1.454.979)	$ (2.326.039)	$ (638.679)
$ (568.387)	$ (203.175)	$ (211.425)	$ (372.604)	$ (31.119)	$ (1.454.979)	$ (2.326.039)	$ (638.679)
$ (579.754)	$ (207.239)	$ (215.653)	$ (374.467)	$ (31.430)	$ (1.454.979)	$ (2.326.039)	$ (638.679)
$ (591.349)	$ (211.383)	$ (219.966)	$ (376.340)	$ (31.744)	$ (1.454.979)	$ (2.326.039)	$ (638.679)
$ (603.176)	$ (215.611)	$ (224.366)	$ (378.221)	$ (32.062)	$ (1.939.972)	$ (2.326.039)	$ (638.679)
$ (615.240)	$ (219.923)	$ (228.853)	$ (380.113)	$ (32.382)	$ (1.939.972)	$ (2.326.039)	$ (638.679)
$ (627.545)	$ (224.322)	$ (233.430)	$ (382.013)	$ (32.706)	$ (1.939.972)	$ (2.326.039)	$ (638.679)
$ (640.096)	$ (228.808)	$ (238.099)	$ (383.923)	$ (33.033)	$ (1.939.972)	$ (2.326.039)	$ (638.679)
$ (652.897)	$ (233.384)	$ (242.860)	$ (385.843)	$ (33.364)	$ (1.939.972)	$ (2.326.039)	$ (638.679)

Figure 53 - Operating and Voyage Costs for the second scenario of study.

SUM COSTS	Revenue	IDEAL CASH FLOW	Taxes	CASH FLOW AFTER TAXES	Discounted CASH FLOW
$ -		$ (19.133.969)		$ (19.133.969)	$ (19.133.969)
$ (3.832.158)	$ 6.421.325	$ (376.598)	$ -	$ (376.598)	$ (348.702)
$ (4.418.411)	$ 6.421.325	$ (938.934)	$ -	$ (938.934)	$ (804.985)
$ (4.629.964)	$ 6.421.325	$ (1.126.569)	$ -	$ (1.126.569)	$ (894.307)
$ (4.899.428)	$ 6.421.325	$ (1.372.116)	$ -	$ (1.372.116)	$ (1.008.546)
$ (4.917.944)	$ 6.421.325	$ (1.366.715)	$ -	$ (1.366.715)	$ (930.163)
$ (5.179.298)	$ 6.421.325	$ (1.604.150)	$ -	$ (1.604.150)	$ (1.010.887)
$ (5.198.502)	$ 6.421.325	$ (1.599.437)	$ -	$ (1.599.437)	$ (933.256)
$ (5.218.061)	$ 6.421.325	$ (1.595.078)	$ -	$ (1.595.078)	$ (861.771)
$ (5.237.980)	$ 6.421.325	$ 1.183.345	$ (2.367)	$ 1.180.978	$ 590.783
$ (5.258.268)	$ 6.421.325	$ 1.163.057	$ (2.326)	$ 1.160.731	$ 537.643
$ (5.763.924)	$ 6.421.325	$ 657.401	$ (1.315)	$ 656.086	$ 281.384
$ (5.784.970)	$ 6.421.325	$ 636.355	$ (1.273)	$ 635.082	$ 252.200
$ (5.806.406)	$ 6.421.325	$ 614.919	$ (1.230)	$ 613.689	$ 225.652
$ (5.828.240)	$ 6.421.325	$ 593.085	$ (1.186)	$ 591.899	$ 201.519
$ (5.850.480)	$ 6.421.325	$ 570.845	$ (1.142)	$ 569.704	$ 179.594
$ (6.358.126)	$ 6.421.325	$ 63.199	$ (126)	$ 63.073	$ 18.410
$ (6.381.201)	$ 6.421.325	$ 40.125	$ (80)	$ 40.044	$ 10.823
$ (6.404.705)	$ 6.421.325	$ 16.620	$ (33)	$ 16.587	$ 4.151
$ (6.428.648)	$ 6.421.325	$ (7.323)	$ -	$ (7.323)	$ (1.697)
$ (6.453.038)	$ 6.421.325	$ 7.621.875	$ (15.244)	$ 7.606.631	$ 1.631.989

Figure 54 - Global cash flow for the second scenario of study