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

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ABSTRACT: This paper is focused on the identification, study, and implementation of methodologies new developed and 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, taking also into consideration market phenomena, such as seasonality of the route's demand.

Finally, the sizing method created in the project is tested in two cases study, using the previously operated vessel as a comparison, analyzing the differences between the ships-generated and the one used in the route previously. This paper ends with conclusions, comments, and recommendations, especially regarding the improvement of the method and future steps on the development of the numerical tool.

KEYWORDS:

Short Sea Shipping, Design Modeling, Ro-Pax ferry modeling, Investment Analysis, Madeira Island, Liner Shipping, Transportation demand, Cost models, Insular Transportation

1 INTRODUCTION

This paper 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.

It is important, before starting, to understand the background that underpins this project. The European Union (EU) has been promoting, since the begging 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. More than this, 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. 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.

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). Being classified as an SSS route any route between European ports, or between a European port and another non-European port that shares the same waters that surround Europe, 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 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 Island (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, and the sizing of a ship for this SSS route, evaluating operating costs, voyage costs, and capital costs. The model may assist the governmental and private entities when evaluating a possible contract to operate in this route. 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, 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.

This paper is structured in six chapters that, in order, introduce the transportation problem, presenting important aspects of the route. Then the literature review and the methodology are presented, covering the main expressions and assumptions used during the development of the paper. Finally, two cases of study are presented, followed by the conclusions of the paper and recommendations for future works.

2 THE TRANSPORTATION PROBLEM: FERRY PORTUGAL - MADEIRA

Since its discovery, the Madeira archipelago draws attention because of the appropriate climate for agriculture and the vast natural variety. 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, reinforcing the strong phenomenon of the seasonality on the demand for the service.

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, but it is important to notice that the Portuguese government also 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, between the options, the port of Portimão has been chosen for the project purposes. Most because of its structure for handling passengers and roll-on/off cargo, and its distance to the archipelago.

2.1 Ship's and route characteristics

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;
- 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 two ports. From these yearly minimum number of voyages, 24 trips must be done in a weekly frequency, between the dates June 1st and September 15th. More than this, the Portuguese government also predefines the maximum tariffs that can be charged from each different type of ticket.

2.2 Government positions on the route

Further, the State also incentives the return of the route with some financial aids, especially in the first years of the operation. Two main inducements are carried out, first for the residences users of the RAM, covering part of the tickets for those. Since the project takes the ship operator's perspective in the financial analysis, all the subsidies applied in ticket prices are not relevant once the government pays back the difference in those ticket values for the service provider.

Another big incentive made, is to apply an extraordinary reduction in the port tariffs in the first years of the 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 incentives 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.

2.3 Traffic and seasonality

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.

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 1, according to the APRAM reports from this period. Even though this phenomenon is very strong and may difficult the operation, during its first years, 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.

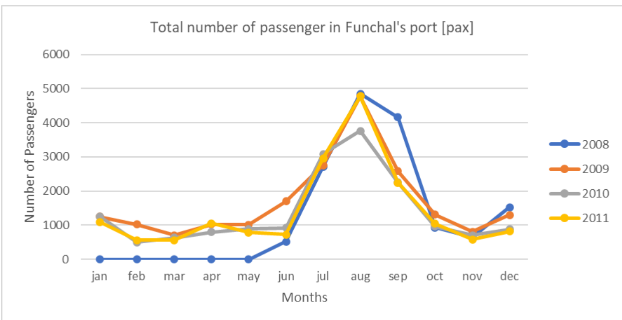

Figure 1 - Total number of passenger in/out Funchal's port

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 paper.

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 2. And, 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.

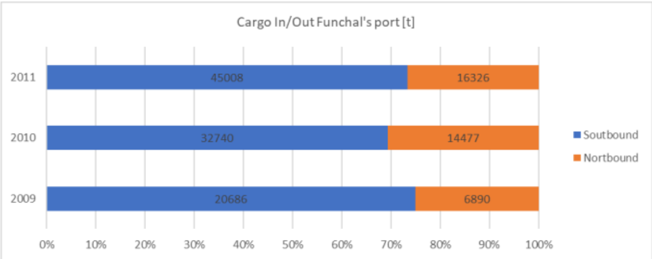

Figure 2 - Cargo in/out Funchal's port in tonnage

Taking into consideration the different request 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, and for this, a mathematical tool was developed in Excel. In short, the method uses real statistics historic for a given freight rate and service speed, to estimate the possible behavior of each class demand. Being this essentially an economic hurdle, related to the concept of elasticities of demand, and knowing that this 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. 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. And 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). An example of these matrices is illustrated below in Figure 3.

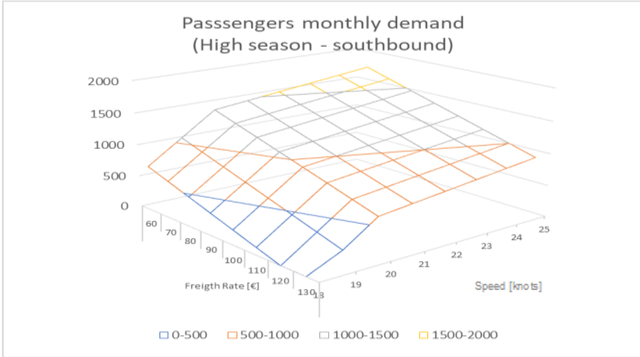

Figure 3 - Monthly demand of passengers southbound in high season

For the cargo demand, the analysis must be further, because of the lack of monthly details in the data provided by the port of Funchal reports. So, to obtain the variation of the demand each month 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.

To solve the problem of the divergence of imports and exports of the RAM, 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 is possible for the numerical tool to have more elasticity in the guesses, the matrix created is illustrated below in Figure 4.

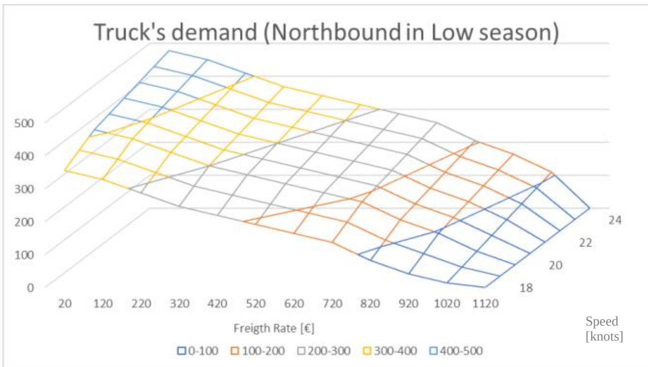

Figure 4 - Monthly demand for trucks northbound in Low season

Once diagrammed 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. According to the previous service report (SRETC – APRAM, 2016), 50% of the population are in seats, and the rest in cabin, but not provided by type so, it is considered half in two-person cabins and the other half in four-person cabins once in the tool is just defined the seated price ticket. The prices for the cabins 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.

3 LITERATURE REVIEW

Before begging 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. Begging with Quintal (2013), the first work is 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.

The main 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, it is impossible because of the behavior and seasonality of the market.

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 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, pointing out the strategy of the company. Freitas identifies the critical factors for the success of the previous operation, among them, the lack of superstructures in the Funchal port to optimize the Ro-Ro operations, high port tariffs in the RAM ports, and others.

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, which opens the opportunity for the vessel to transport different cargo, such as semi-trailers and containerized cargo. These assumptions avoid the necessity of truck head to be abroad and give the vessel more haulage capacity, not being trustful when computing the revenue or the time in port.

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.

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 the authors 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.

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.

4 METHODOLOGY

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.

4.1 Main Characteristics Calculations

In the numerical tool, the lanemeter capacity is defined 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.

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

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 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, 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 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:

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

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

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

The next step is the calculation of the total resistance of the ship, in order to obtain the main engine power required, for that, the method of Holtrop and Mennen (1982) will be used. 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:

$$L_{wl} = \begin{cases} 1.01 \times Lpp \text{ , } if\ is\ Single\ Screw \\ 1.035 \times Lpp \text{ , } if\ is\ Twin\ Screw \\ 1.04 \times Lpp \text{ , } if\ is\ Twin - Skeg \end{cases} \quad [m] \tag{10}$$

$$D_{prop} = \begin{cases} 0.56 \times T_{max} + 1.07 \text{ , } if\ is\ Single\ Screw \\ 0.71 \times T_{max} - 0.26 \text{ , } if\ is\ Twin\ Screw \\ 0.85 \times T_{max} - 0.69 \text{ , } if\ is\ Twin - Skeg \end{cases} \quad [m] \tag{11}$$

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.

Table 1 - Difference in % between the results of Mumford's formula variations

Ship Type	Original Mumford's formula	Modified Mumford's formula	Modified Mumford formula with 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

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

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

$$R_T = R_F(1 + K_1) + R_{APP} + R_w + R_B + R_{TR} + R_A \quad [kN] \tag{12}$$

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, following the equation below:

$$HP_{total} = \frac{R_T \times v}{\eta_h \times \eta_g \times \eta_s \times \eta_r \times \eta_o} \quad [kW] \tag{13}$$

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 (13) above, giving the P_{MCR} value.

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

$$P_{EL} = 2432 + 0.14944 \times P_{MCR} \quad [kW] \tag{14}$$

4.2 Weights Calculations

The next is to estimate the lightship weight. To do it is necessary to first define hull weight, machinery weight, and equipment weight. Beginning with the hull weight estimation using the following expression, according to Ventura (2016).

$$W_H = 0.0313 \times L_s^{1.675} \times B^{0.850} \times D^{0.280} \quad [t] \tag{15}$$

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

$$W_M = 1.88 \times P_{MCR}^{0.60} \quad [t] \tag{16}$$

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:

$$W_E = 0.5166 \times (L \times B \times D)^{0.75} \quad [t] \tag{17}$$

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.

4.3 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. For the hull, it can be roughly estimated by the following expression (Carreyette, 1977):

$$Mh_H = 227 \times \frac{W_H^{\frac{2}{3}} \times L_{pp}^{\frac{1}{3}}}{C_b} \quad [M.h] \tag{18}$$

Where,

$$CP_H = Mh_H \times u_{Mh} \quad [US\$] \tag{19}$$

$$CM_H = W_H \times u_{steel} \quad [US\$] \tag{20}$$

The price of marine steel can vary a lot, especially depending on where the material is, the quality, and 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 Estaleiros Navais de Viana do Castel*o (ENVC, source: Ventura, 2016) the average price of the manhour labor is around \$ 20.00, and this value is also used in the numerical tool.

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:

$$Hh_E = Z \times L \times B^{\frac{1}{2}} \quad [M.h] \tag{21}$$

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.

$$CP_E = W_E^{0.95} \times u_E + Hh_E \times u_{Mh} \quad [US\$] \tag{22}$$

The machinery costs can be expressed by:

$$CP_M = 1.6 \times \left(\frac{P_{MCR}}{100}\right)^{0.82} \times u_M + CF_M \quad [US\$] \tag{23}$$

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:

$$CF_M = Mh_M \times u_{Mh} \quad [US\$] \tag{24}$$

Where,

$$Mh_M = 1600 \times \left(\frac{P_{MCR}}{100}\right)^{0.6} \quad [M.h] \tag{25}$$

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.

4.4 Costs structure for Ro-Pax ships

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 the numerical tool calculates the total yearly amount, but only consider the operational period.

In this sense, 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, which means, it is only considered 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.

First starting with the capital costs, which 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.

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.

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 the equation below.

$$CRF = \frac{\tau(1+\tau)^t}{(1+\tau)^t - 1} \tag{26}$$

Then, the theoretical annuity of the ship is calculated summing the initial investment, installments, interest and residual value of the vessel, all the costs brought to the present value. 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.

Secondly, 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, and 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 Portuguese crew members registered in MAR (*Registo Internacional de Navios da Madeira*), being so, the average annual cost of the crew is assumed to be $K = 41{,}000\ USD$. The formula used to guess the annual costs for manning is shown below:

$$\$\ Manning_{cost} = K \times N^{0.95} \quad [US\$/year] \qquad (27)$$

The Store and Consumables are the costs that mainly depend on cabin store capacity, in other words, depends on the size of the crew. And follows the equation below.

$$\$S\&\ C_{costs} = K_1 \times N + K_2 \times CN^{0.25} + K_3 \times HP^{0.7} \qquad (28)$$

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

$$\$M\&\ R_{costs} = K_1 \times \$P + K_2 \times HP^{0.66} \ [US\$/year] \qquad (29)$$

The coefficients above are assumed as $K_1 = 0.0035$ 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. 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:

$$\$P\&I_{costs} = K_1 \times \$P + K_2 \times GT \ [US\$/year] \qquad (30)$$

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 2 shows the formulae used for the calculations of the periodic costs during the twenty years of operation of the vessel:

Table 2 - Periodic maintenance formulae used.

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	$\frac{2.5}{100} \times \$P$	$[USD/year]$

The voyage costs have two main components:

- Fuel costs
- Port costs

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. And then, the consumption becomes:

$$F_m = SFOC_m \times P \times t \times \frac{\eta_{main}}{1000000} \times 1.03\ [L/trip] \qquad (31)$$

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. 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 theoretical 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. At the same time is also calculated the SFOC of the Genset, using the average consumption rate and the fuel density. The formula (31) is used for the 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, for both regulations, the vessel is considered as a regular linear of a Ro-Ro ship, which results in some reductions in some costs. After that, the inducements explained earlier are applied over the port costs.

4.5 Validation of the Model and methodology corrections

To trust in 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. Table 3 shows the characteristics of the ships used for the corrections in the methodology.

Table 3 - Ship's characteristics

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. Figure 5 and Figure 6 show the deviation distribution of the characteristics calculated from the real values.

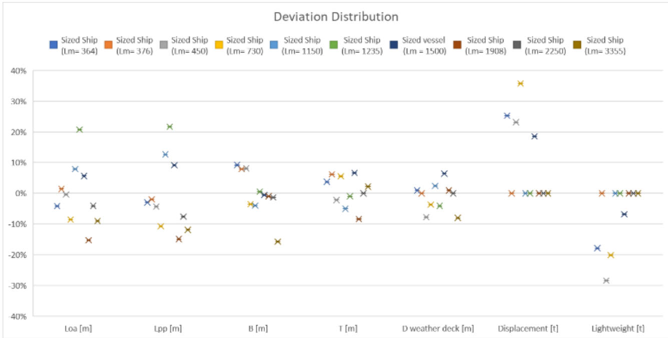

Figure 5 - Deviation distribution for main particulars

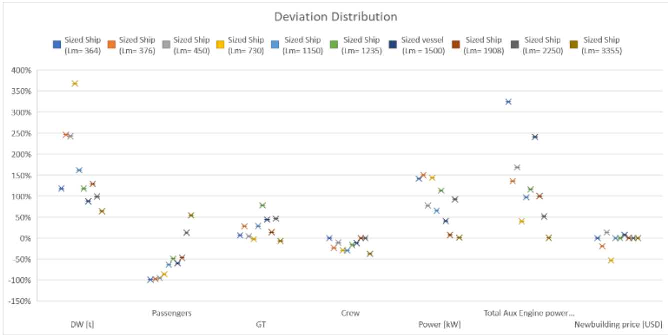

Figure 6 - Deviation distribution for other characteristics

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 (32):

$$F(x) = f(x) + C(Lmt) \qquad (32)$$

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. 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.

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.

5 CASE STUDY

5.1 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 (operated in 2011), in an attempt to replicate similar conditions as the previous operations of the route.

In the previous operation regarding the tariffs applied to passenger's and the car's the tickets do not take into consideration the direction or period 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.

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 most of the income), but also respecting the government request of 24 trips between the 1st of June and 15th of September. It is set that the ship will have four departures from Portimão per month.

For the design parameters, it settled 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. Table 4 shows the comparison between sized and real ships in percentage.

Table 4 - Specifications of the operated and sized vessel, with deviations in %

	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 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, 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.

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 5.

Table 5 - Investment parameters defined in the case study

Discount rate	8%
Scrap Value [USD]	$20\%\ of\ \$P$
Taxes	20%
Scrap value	20% of $P

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 (represented by the annuity), and added to it, the operating, voyage costs (represented by fuel and port costs), and taxes.

The annual cash flow is calculated and presents losses during all the years, calculating the Net Present Value (NPV) of the entire 20 years of operation we arrive at the total negative value of:

$$NPV = \$ \quad (27.683.511) \qquad [USD] \qquad (33)$$

5.2 Newbuilt Ro-Pax

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. Comparing both vessels sized, it is possible to notice that the second scenario vessel is slightly larger than the first one, as shown in Table 6. Meaning greater revenue, but also greater investment for building it and operating it.

Table 6 - Comparison between both sized ships

	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%**

After calculating all costs related to the building and operation of the vessel in 20 years of operation, it is possible to see the operation has losses during the first years, until the end of the payment of the bank loan. Then during the following years, it has profit, that starts at approximately $600{,}000\ USD$ and, as the financial incentives vanish, also does the profit. The total NPV of the 20 years of operation is negative, with the value exposed below:

$$NPV = \$ \quad (20.364.939) \qquad [USD] \qquad (34)$$

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 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 paper 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 paper 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. Besides, the tool also forecasts the capital and operating costs related to this operation. 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 first problem appears before the start of the methodology - in the data source - since little technical information can be found about the route. Limited additional data was revealed by entities related to the operation to develop a better numerical tool and turns out to be necessary to undertake the study over several market behavior assumptions to try to create sufficient information to develop the project. 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.

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

Becomes evidentially that 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.

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 probably also for its profit.

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 and market areas are used, even including laws review in the process. All methodology's calculations respect the different requirements of the route's operation and international rules.

6.2 Recommendations

As this paper 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, trying to narrow the regressions created to illustrate real-life situations with more accuracy. 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 paper are used qualitatively.

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. 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.

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.

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