APPROACH FOR THE DESIGN OF SPECIALIZED SHIPS: THE CASE OF CARGO TRANSPORT TO AN OCEAN ISLAND

(Reference No: IJME637, DOI No: 10.5750/ijme.v163iA2.756)

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KEY DATES: Submitted: 24/03/20; Final acceptance: 03/03/21; Published 12/07/21

SUMMARY

The island of Fernando de Noronha (FN) is a marine protected area, located about 293 nautical miles from Recife, Brazil. Supplies are transported out by improvised boats and the main freight contractor, the Administration of FN (AFN) spends large sums with outsourced shipping services, some of which could be redirected to problems of major concern such as health, environment and education. Using a sequence of five steps, including the construction of a database, mathematical simulation and economic feasibility analysis, it was possible to develop a preliminary design for a specialized economically viable vessel, which meets the requirement, draught limitations and needs of the island of FN. It is shown that the approach is feasible through the construction of a mathematical optimization model and a design of a vessel of about 450 tons of displacement that allows cost savings to AFN of around US$ 1.76M per year.

NOMENCLATURE

AFN	Administration of Fernando de Noronha
B	Beam [m]
BNDES	Brazilian Development Bank
BRL	Brazilian Reais (currency) ≈ 4.20 USD
$Cargo$	Real load of vessel in tonne
Cb	Block coefficient
C_{acquis}	Acquisition cost of vessel in US$
C_{cons}	Consumable cost of operation in US$/trip
C_{fuel}	Fuel cost of operation in US$/liter
C_{lub}	Lubricant cost of operation in US$/liter
C_{load}	Cost of loading operation in US$/trip
C_{oper}	Cost of vessel operation in US$/trip
C_{unload}	Cost of unloading operation in US$/trip
$Cons_{fuel}$	Fuel consumption in g/kWh
$Cons_{lub}$	Lubricant oil consumption in g/kWh
$Cons_{water}$	Crew water consumption in kg per person per day
$Crew$	Vessel crew
D	Depth [m]
DWT	Deadweight [ton]
EFA	Economic Feasible Analysis
FD	Freight demand in tons per year
$Fleet$	Number of identical vessels to meet the freight demand
FN	Fernando de Noronha
Fn	Froude number
g	Gravity constant in m/s²
h_{work}	Hours work per day
K_1	Proportionality constant of acquisition cost in US$/DWT
K_2	Operational cost constant
$Life$	Vessel life operation in years
LOA / L	Length overall [m]
Lpp	Length between perpendiculars [m]
MCR	Engine consumption power [kW]
Mr. NR	Similar existing vessel that transports cargo from Recife to FN
N_{trip}	Number of trips per year
$Need_{trav}$	Vessel size for operation in t
$Route$	Vessel route in nautical miles
T	Draught [m]
T_{loadR}	Loading time of vessel in port of Recife in hours
T_{manut}	Maintenance time in days per year
T_{sea}	Round trip vessel in hours
T_{total}	Total vessel operating in hours
$T_{unloadFN}$	Unloading time of vessel in FN port in hours
T_{wait}	Waiting time in days at ports
Tx_C	Cargo handling charge fee per day
Tx_{fuel}	Fuel oil price per kilo
Tx_L	Mooring fee by vessel length per day or fraction
Tx_T	Goods handling fee per tonne
USD	United States Dollar (currency)
V_{loadR}	Loading speed at departure port in t/h
V_S	Service speed [knots]
$V_{unloadFN}$	Unloading speed at arrival port in t/h
W_{crew}	crew weight in tonne
W_{fuel}	Oil fuel weight in tonne
W_{lub}	Lubricant oil weight in tonne
W_{water}	Water weight consumed in tonne
Δ	Displacement
ρ_{water}	Sea water density in t/m³

1. INTRODUCTION

This study arises from the intention to contribute to the resolution of two problems, one as a consequence of the other: (i) the need for a preliminary ship design to transport cargo to an archipelago; (ii) it is considered that there is no systematic procedure or structured approach in the literature for the conceptual and preliminary design of specialized vessels. These two problems will be contextualized below.

1.1 THE CASE OF FERNANDO DE NORONHA

FN is an archipelago 542 km off the northeast coast of Brazil (03°51'S, 32°25'W), and lies 297 nautical miles from Recife, the capital of the state of Pernambuco (Figure 1). The archipelago consists of 21 islands, has approximately 3,000 residents and receives an average of 100,000 tourists per year (Coelho, 2019d; IBGE, 2019; Marinho, 2019). With a total area of 2,600 hectares, 2/3 of AFN is a National Marine Park (PARNAMAR) and 1/3 is an Environmental Protection Area (EPA). The PARNAMAR and EPA are assigned to protect the fauna, flora and natural resources of the island, in order to ensure humans use the space rationally (ICMBio, 2017).

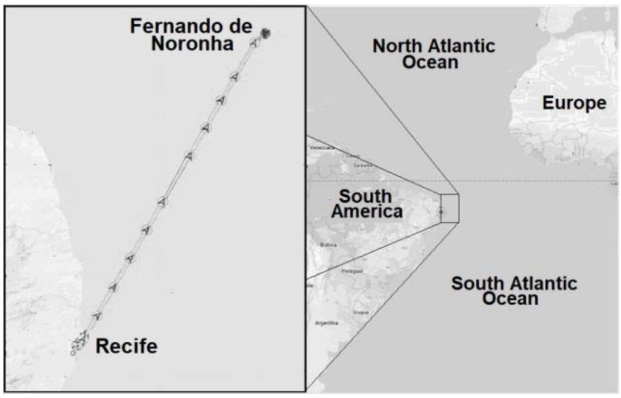

Figure 1: Route between Recife and FN

FN faces various social and environmental problems. For example, regarding education, the illiteracy rate of the island is around 17% and 58% of the population aged over 10 years old are uneducated or did not complete elementary education (BDE, 2010; Condepe, 2012). Another example is the population growth. As it is considered a tropical paradise, FN attracts many tourists. This high additional population contributes to shortages of water and energy, these being basic needs for humans, work and protecting the environment. A threat the archipelago faces is that its natural resources will be depleted in the coming decades due to socio-environmental conflicts. Thus, the island seeks to adopt a sustainable model of development to preserve its resources, the residents' lifestyle and tourists (Coelho, 2019a, 2019c).

In addition to the lack of resources, other problems caused by the increase in the number of residents and tourists are the excessive generation of waste, and the lack of selective collection and treatment of waste. The island generates 240 tons of garbage per month, i.e. an average of 8 tons is collected daily, most of which is shipped to Recife (ICMBio, 2014; Coelho, 2019b, 2019a).

Currently, waste is transported in vessels from the port of Recife (Coelho, 2019c); they carry supplies to the island and return with tons of trash for disposal. Linked to this, a new problem arises concerning the vessels that transport this cargo from Recife to FN.

The problem of shipping supplies from Recife to FN is not recent. It is mainly done by vessels not designed for oceanic cargo transport, namely tugboats, barges, fishing boats and support boats, all of which have been adapted and not specifically designed to meet the characteristics of transporting cargo to and from FN. The main difficulties about this are:

(i) The infrastructure of the port of Santo Antônio in FN. The berth is small and there is no crane, and the only pier is 50 m long with a limitation of only 4 m in depth.;

(ii) The trip includes oceanic navigation, with waves around 2.5 m high during the summer, with winds of up to 25 knots. According to (Dias, 2013), during the months of December to February, the waves near the Brazilian coast are stronger due to the trade winds and tropical and extratropical cyclones that intensify in the northern hemisphere during this time of the year. Thus, there is the formation of high periods waves (i.e., from 8 to 13 sec) that reach the coast of the island of FN. Another study (Farias and Souza, 2012), states that the northeast coast of Brazil is located in an area quite exposed to waves of great length between the months of January to March.

The second factor worsens the problems arising from the first factor, because the infrastructure of the port can only cater for small vessels and it is these that are most affected by adverse weather on the high seas.

Few vessels that carry cargo to FN are fit for oceanic navigation. This place the safety of cargo and safeguards to protect human life and environmental at risk. Moreover, freight charges are high, thus increasing the cost of living not only for residents and tourists, but especially expenditure by the Administration of FN (AFN).

AFN is the main buyer of freight on FN. Freight cost about $1,500 Brazilian Reais (BRL) per ton of cargo in 2017. AFN estimates that it orders about 150 tons of cargo per week. This represents an annual cost of around 11,7 million BRL only on freight (i.e., approximately 2 million US Dollars) which is approximately 9% of FN's Gross Domestic Product (GDP). Potentially, savings on these regular costs could be significant and such saving could be allocated to the budgets for the environment, education, public sanitation, tourism, public health, energy and other areas of public management on FN for which there is a shortage of funding.

Thus, we raise the following questions, instead of paying third parties to carry freight, what if the AFN invests in building its own vessel? What would be a viable conceptual and preliminary design for that vessel? How much would it cost to purchase, operate and maintain it? Would it be feasible to get funds from the Brazilian Development Bank (BNDES)? Could the annual amount saved on freight cover these costs? After meeting such costs, how much would be left for AFN to invest in other sectors? This paper evaluates these questions and so contributes to the sustainability of FN. The focus of this paper is on a solid cargo vessel (e.g., bottled drinking water, food, building materials) based on the hypothesis that the AFN is not interested in investing in a fuel transportation vessel, as this market has been dominated by Agemar since 1995 (AGEMAR, 2018).

It may be more advantageous for the AFN to invest in its own vessel by seeking a loan from BNDES if this loan could be repaid from the monthly amount saved on freight and enough was left to invest in other sectors.

1.2 SHIP DESIGN METHODOLOGY

Ship design is based on a sequential and iterative approach that is influenced by a variety of technological, political-economic environmental and other factors. Designing a ship is a multipurpose, large-scale system-engineering project with sometimes conflicting requirements, resulting from the design constraints and meeting optimization criteria (Xuan *et al.*, 2009).

As there is no specific procedure to design vessels, currently the most commonly used one is that proposed by (Lamb, 2003), which is frequently divided into four stages: conceptual, preliminary, contract and detailed design. The conceptual and preliminary design phases, which precede signing a contract with a shipyard, are the focus of this paper. However, the methodology proposed by Lamb is not applicable for our case since it is appropriate for larger vessels only, because their study was based on a pattern of large similar cargo ships. Thus, new methodologies or guidelines for the design of specialized vessels contribute to improving the state of the art in ship design. This paper puts forward a suggestion of this nature.

1.3 OBJECTIVES

First, an approach for the conceptual and preliminary design of specialized vessels is proposed. For each step of the approach, all necessary starting points, models, basic data and end points will be described. The approach provides guidelines for: (i) total cost optimization (purchase, operation and maintenance throughout the lifetime of the vessel), considering variables such as its main dimensions, speed, travel time and vessel fuel; (ii) the EFA of the optimized vessel in order to analyse the return on investment, payback and financing; (iii) specific hull form design; (iv) propeller system design; and (v) structural and stability analysis.

The remainder of this paper is structured as follows. In section 2 (Approach), the systematic procedure for the conceptual and preliminary design of a specialized vessel is presented and the specific methods are explained. In section 3 (Results) the approach is validated, and its proposed use by AFN is illustrated. The approach is explained step by step so that the reader can have a better practical understanding of each step. Also, the case specific EFA and preliminary ship design are presented. In section 4 (Discussion), some discussions are made based on the obtained results from the vessel and its economic viability. Finally, in section 5 (Conclusions), some conclusions are drawn, and suggestions are made for future lines of research.

2. APPROACH

The approach is structured according to the following subsections. It is worth noting here that our approach makes use of the Evans Spiral, i.e..: an iterative method of refinement that consists of defining a ship's characteristics, where each round in the spiral represents an iteration (Evans, 1959). In this paper, we present results of the second round of our Evans Spiral (**Figure 2**). The first round has already been undertaken in previous studies (Eduardo *et al.,* 2018; Santos *et al.,* 2018). Following the proposal by (Andrews, 2018) on design constraints affecting ship layout, the spiral presents the main problem areas that affect the design phases of a vessel that meets the needs of FN.

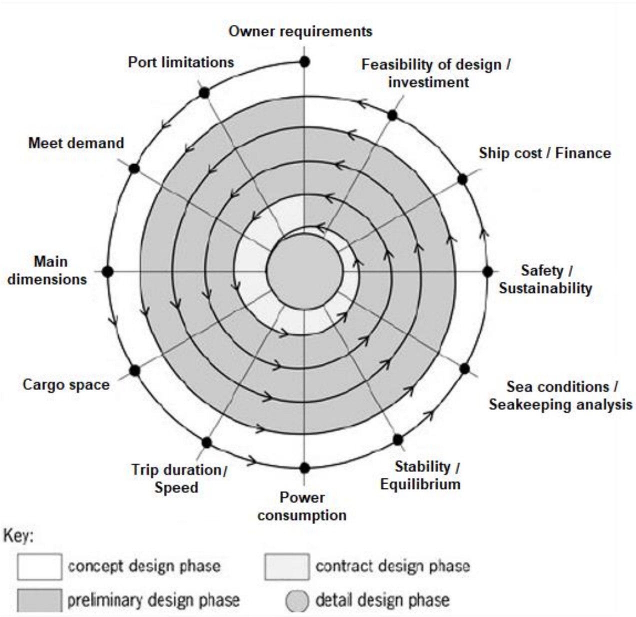

Figure 2: Vessel Evans Spiral. Adapted from (Vossen, Kleppe and Hjørungnes, 2013; Andrews, 2018)

According to (Andrews, 2018), the first design decision to be made is the style of ship design that will be adopted. This decision is seen as having the greatest impact on the design phases, ranging from the type of ship design to the generic characteristics of ship quality and operation.

Following this approach and considering the case of FN, the style of ship design adopted was that of small cargo ship, to meet the island's demand. In addition, the vessel must be economically viable for AFN and contribute to the sustainability of the protected area.

2.1 DATA COLLECTION

2.1 (a) Data Collection and Database Construction

Given the shipowner's requirements, a database can be created with a large number of physical, operational and economic characteristics from existing similar vessels. The information gathered should include the length overall (LOA), length between perpendiculars (LPP), maximum beam (B), draught (T), deadweight (DWT), power consumption (MCR), service speed (Vs), dept (D) and block coefficient (Cb).

Data on vessels with a DWT lower than 500t and LOA of up to 50m were collected, considering the current limitations of the FN port. This information was taken from 7 different sources, such as FleetMon (FleetMon, 2017), Vessel Finder (Vessel Finder, 2017) and Marine Traffic (Marine Traffic, 2017). The information not obtained from these sources such as length between perpendiculars (LPP), depth of vessel (D), block coefficient (CB) and displacement (Δ), was estimated using empirical formulations (Ventura, 2009; Papanikolaou, 2014).

Barges were not considered in the database, based on the definition of barge in NORMAM-01 (DPC, 2005a), i.e.: a barge is any cargo vessel which generally has the following characteristics: it is not manned; does not have its own propulsion system; beam and draught ratio is greater than 6.0; beam and depth ratio is higher than 3.0.

2.1 (b) Data Processing

Here the designer should build correlation curves for the characteristics collected (e.g., LxB, MCRxVs, DWTxL, BxD, DWTxD, CBxDWT and LxT).

Because we do not want our ship to be similar to adapted vessels that were not designed for cargo transportation (e.g., barges, fishing vessels), outliers were removed from the database. The criteria for removing outliers may be, e.g.: slender ships, draught limitations of the port and barges.

As a result of this step, the following correlation functions should be defined: L(B); MCR(Vs); DWT(L); B(D); DWT(D); CB(DWT) and L(T), as shown below in Table 1, in Parameterization Curves.

Table 1: Definition and values of parameters and variables, where t is tons, kWh is kilowatt hour, g is grams, h is hour, m is meters and s is second.

Parameterization Constants	Symbol	Description	Value	Considerations	Reference
Water density	ρ_{water}	Sea water density in t/m³	1.025	Average density of sea water on the surface	(APRH, 2007)
Gravity	g	Gravity constant in m/s²	9.81		
Maintenance time	T_{manut}	Maintenance time in days per year	60	Mr. NR vessel estimated maintenance time	Personal communication (May/2017)
Service Life	$Life$	Vessel life in years of operation	25	Average service life of a steel vessel	(Lamb, 2003)
Route	$Route$	Vessel route in nautical miles	300	Distance travelled by vessel from Recife to FN	(Brasil, 1974)
Unloading speed	$V_{unloadFN}$	Unloading speed at arrival port in t/h	20	Estimated unloading speed of Mr. NR	Personal communication (May/2017)
Loading speed	V_{loadR}	Loading speed at departure port in t/h	20	Estimated loading speed of Mr. NR	Personal communication (May/2017)
Fuel consumption	$Cons_{fuel}$	Fuel consumption in g/kWh	200	Engine used by Mr. NR	(Scania, 2017)
Lubricant oil consumption	$Cons_{lub}$	Lubricant oil consumption in g/kWh	0.3	Engine used by Mr. NR	(Scania, 2017)
Water consumption	$Cons_{water}$	Crew water consumption in kg/(person.day)	150		(Pereira, 2017)

Waiting time	T_{wait}	Waiting time in days at ports of Recife and FN	2	1 day in Recife and 1 day at FN	Personal communication (May/2017)
Crew	$Crew$	Vessel crew (person)	6	Crew of a vessel carrying cargo from Recife to FN	Personal communication (May/2017)
Freight demand	FD	Freight demand in tons/year	7800		Personal communication (May/2017)
Proportionality constant	k_1	Proportionality constant of the acquisition cost in US$/DWT	3,819.34	Acquisition cost per DWT for a new vessel	Section 2.2
Mooring fee by vessel length in discharging port	Tx_L	Fee in US$ per day or fraction, without movement of goods	54.04	Vessel over 10 m in length	(Noronha, 2019)
Goods handling fee per tonne at arrival port	Tx_T	Fee in the case of movement of goods in US$ /ton	1.02	Handling from 201 to 1000 tons of cargo	(Noronha, 2019)
Cargo handling charge at departure port	Tx_C	Cargo fee in US$ per day at departure port	238.71	US$ 238.71 per day in Recife port	Personal communication (May/2017)
Fuel consumption fee	Tx_{fuel}	Fuel oil price per kilo	1.09	US$ 0.95 per liter of fuel density of de 0.87 kg/l	(Agência Nacional do Petróleo, 2019)
Operating cost constant	k_2	Constant calculated to estimate vessel's operational cost	412.95		Section 2.2

Parameterization Functions	**Symbol**	**Considerations**	**Function**
Power based on Service Speed	$MCR\ (Vs)$	Similar Ships Method	$97.633 * Vs - 608.74$
Deadweight based on Length	$DWT(L)$	Similar Ships Method	$0.376 * L^2 - 12.902 * L + 249.93$
Displacement based on block coefficient, length, draught, beam and water density	$Disp\ (C_B, L, T, B, \rho_{water})$	Definition of block coefficient (Rawson and Tupper, 2001)	$C_B * L * T * B * \rho_{água}$
Block coefficient based on deadweight	$C_B\ (DWT)$	Similar Ships Method	$0.0003 * DWT + 0.5926$
Length based on draught	$L\ (D)$	Similar Ships Method	$10.204 * D - 5.3245$
Beam based on depth	$B\ (D)$	Similar Ships Method	$1.1874 * D + 2.3789$
Depth based on draught	$D\ (T)$	Similar Ships Method	$1.391 * T + 0.3206$
Froude number based on service speed	$Fn\ (Vs)$	Definition	$Vs * (1.852/3.6) * \sqrt{g * L}$
Work hours	h_{work}	Hours worked per year, not considering vessel maintenance time	$(360 - T_{maint}) * 24$
Oil fuel weight	W_{fuel}	Based on vessel operating time at t	$(BHP * T_{sea} * Cons_{fuel})/1000000$
Lubricant weight	W_{lub}	Based on vessel operating time at t	$(BHP * T_{total} * Cons_{lub})/1000000$
Consumption water weight	W_{water}	Based on vessel operating time at t	$(Cons_{water} * ({}^{T_{sea}}/_{(24 * 2)} * Crew))/1000$
Crew weight	W_{crew}	Average weight of each crew member plus their luggage: 150 kg	$(Crew * 150)/1000$
Travel need	$Need_{trav}$	Minimum vessel size for operation in t	$(W_{fuel} * W_{lub} + W_{water} + W_{crew})$
Ship cargo capacity	CDW	Real load of vessel operating in t	$DWT - Need_{trav}$
Sea time	T_{sea}	Round trip vessel time in h	$2 * Route/Vs$
Loading time	T_{loadR}	Loading time of vessel in departure port	$Cargo/V_{loadR}$
Unloading time	$T_{unloadN}$	Unloading time of vessel in arrival port	$Cargo/V_{unloadFN}$
Total time	T_{total}	Total vessel operating time in h	$T_{sea} + T_{loadR} + T_{unloadFN} + (T_{wait} * 24)$
Number of trips	N_{trip}	Number of trips made per year	$Dem/(Cargo * Fleet)$

Costs	**Symbol**	**Description**	**Consideration**	**Function**	**Reference**

Loading cost	C_{load}	Cost of loading operation in Recife port per trip	US$ 238.71 per day	$Tx_C * T_{loadR}/24$	Personal communication (May/2017)
Unloading cost	C_{unload}	Cost of unloading operation in FN port per trip	Loading and unloading cost from 201 to 1000 tons	$Tx_L * Carga + Tx_T * T_{unloadNF}$	(Noronha, 2019)
Fuel cost	C_{fuel}	Fuel cost of operation	US$ 0.72 per liter of fuel and density of 0.87 kg/l	$Tx_{fuel} * W_{fuel} * 1000$	(Agência Nacional do Petróleo, 2019)
Lubricant cost	C_{lub}	Lubricant cost of operation in US$ per trip		$85.36/W_{lub}$	May/2017
Operational cost	C_{oper}	Operational cost of the vessel in US$ per trip	Crew, maintenance, repairs, materials, insurance and administration costs	$k_2 * DWT$	Section 2.2
Consumable cost	C_{cons}	Consumable costs of operation in US$ per trip		$5 * DWT * T_{total}/24$	Personal communication (May/2017)
Acquisition cost	C_{acquis}	Acquisition cost of vessel in US$		$k_1 * DWT$	Section 2.2

Restriction	**Considerations**
$0.55 < C_B < 0.89$	Characteristic block coefficient of barge vessels and PSVs
$1 < T < 3$ and L < 50	Limitations of FN port
$3 < D < 5.5$	Database
$1 < Fleet < \infty$	Number of identical vessels in the fleet will be necessary to meet the freight demand at minimum cost
$1 < N_{trip} < 30$	Maximum 1 trip per day
$10 < Vs < 20$	Database
$0.15 < Fn < 0.35$	Database
$1.5 < B/D < 2.74$	Database
$1.67 < B/T < 5$	Database
$3.47 < L/B < 6.9$	Database

2.2 OPTIMIZATION MODEL

Here an optimization model should be built to provide the main characteristics of the vessel and thus the minimum overall cost throughout the lifetime of the service, as shown in Eq. 1:

Minimize:

$$Cost = \Big(\big(C_{load} + C_{unload} + C_{lub} + C_{oper} + C_{cons}\big) * Life * N_{trip} + C_{acq}\Big) * Fleet \quad (1)$$

Where the costs, constants and parameters of the equation are presented and clearly identified in Table 1. Every optimization model is subject to initial conditions (i.e., Parameterization Constants in Table 1), correlating functions or design variables (i.e., Parameterization Functions and Costs in Table 1) and Constraints (i.e., Restrictions in Table 1). For the theoretical background on optimization models, see (Caprace and Rigo, 2010; Duarte *et al.*, 2014). Besides the correlating functions, values, or functions for the parameters in the model must be estimated.

To estimate the acquisition cost (C_{acq}), a proportionality constant of acquisition cost (k_1) was used, which was calculated considering the average value of the acquisition cost of a new vessel with 500 t of DWT. This constant (k_1) was estimated by personal communication and websites (Maritime Sales, 1999). Thus, the acquisition cost will be a function of the vessel's DWT, as shown below:

$$C_{acq} = k1 * DWT \quad (2)$$

Note that the acquisition cost of the vessel is estimated as a function of only the DWT and it does not directly take into account the propulsive machinery (MCR) and service speed (V_s). In this way, ships with identical size (DWT) but designed to operate at different speeds and requiring different MCR will have the same cost. However, in order to make this simple model more realistic to our case, we restrict and ensure that the DWT correlation function and $k_1$was estimated using a database of ships operating in conditions similar to that of our vessel, i.e., MCR and service speed from 120 to 600 kW and 5 to 13 knots, respectively. Therefore, we exclude vessels designed to operate at different speeds and that could unrealistically interfere in the estimated acquisition cost according to equation 2.

The acquisition cost of an old vessel was estimated based on 20 general cargo ships between 37m and 65m in length, built between 1951 and 1959, with a deadweight ranging from 108t to 1300t (Maritime Sales, 1999). It was considered that all of them had reached the total service life (i.e., more than 25 years) and therefore the values obtained were the residual values of each vessel.

The annual depreciation can be estimated using the following equation:

$$\%Depr = \left(\frac{C_{acq_{New}}}{C_{acq_{Old}}}\right)^{1/_{Life}} - 1 \qquad (3)$$

Where:

- $\%Depr$ is the annual depreciation.
- C_{acq_New} is the acquisition cost of a new vessel.
- C_{acq_Old} is the acquisition cost of an old vessel.
- $Life$ is the service life of the vessel.

To estimate the fuel consumption costs (C_{fuel}), we collected data on diesel prices in recent years from websites (Agência Nacional do Petróleo, 2019) and then considered the highest one for this model (i.e., US$ 1.09 per kilo), in order to carry out a more pessimistic analysis, since these commodities are quite volatile.

To estimate operational costs (C_{oper}), the costs related to crew, maintenance, repairs, materials, insurance and management were included in an operating cost constant (k_2). Based on studies and websites (Počuča, 2006; Maritime Executive, 2011; Lloyd's List, 2018; Shipcosts, 2019) it was possible to define percentages of costs included as operating costs (i.e., crew, maintenance, repairs, materials, insurance and management). Thus, after obtaining the percentages of each cost, an operating cost constant was stablished for a vessel with 500 t of DWT, according to what was proposed for the creation of the database.

The crew's wages were obtained from websites (Glassdoor, 2019; Salário, 2019c, 2019b, 2019a, 2020; Salários, 2019; Sheltermar, 2019; Vagas, 2019a, 2019c, 2019b).

Estimating the other parameters (i.e., number of trips; maximum and minimum draught, beam, length and service speed; service life; trip; fleet; consumption; weight) depends basically on the port limitations, vessel operation and shipowner's requirements. See Table 1 for the meaning of this parameters.

At the end of this step, one should have defined constant values and/or functions for all parameters of the model presented in Table 1.

2.3 COMPUTACIONAL MODELLING AND SIMULATION

The mathematical model must be translated into a computer programming language in order to be simulated. There are many computational tools for optimization model building and simulation (e.g., Solver package from MS Excel, LINGO). In this work, we use LINGO (Lingo, 2019), which solves the optimization model by Primal and Dual Simplex solvers, dynamically choosing the best pricing option based upon problem characteristics. For more information about this optimization methods, see references (Ray, Gokarn and Sha, 1995; Caprace and Rigo, 2010).

After building the model in the software, it must be simulated and the results of the design variables should be obtained (see Nomenclature section and Table 1 for nomenclature):

- Optimum values for the vessel's main characteristics (i.e., L, B, D, BHP, DWT, T, Cb);
- Costs tied to vessel operation per time unit (i.e., C_{load}, C_{unload}, C_{fuel}, C_{lub}, C_{oper}, C_{cons}, C_{acquis}).

2.4 ECONOMIC FEASIBILITY ANALYSIS

Based on the results obtained in 2.3, a study is made of the economic feasibility of the project for acquiring a vessel in terms of profit and return on investment.

To carry out the EFA, the following inputs are needed: the costs resulting from the previous step; estimates of revenues and expenses considering inflation rates, taxes, interest rates, depreciation and financing payment instalment. The value of the future inflation rate was estimated using a historical average of the inflation rate over the last 10 years, in this case between 2000 and 2020. A trend was sought between the values to adopt an estimated rate.

The approach is deterministic. Uncertainty in results was considered by estimating parameters from a conservative/pessimistic point of view, i.e., profits were underestimated.

Therefore, we suggest that revenues should be calculated based on freight rate, cargo per trip and number of trips per time unit, as shown in the following equation:

$$Revenues = Freight * Cargo * N_{trip} \qquad (4)$$

For expenses, we suggest calculating according to the sum of the insurance value, instalments ship and vessel total costs per time unit.

The calculated cost and revenue data should be structured into a cash flow and thus the Net Present Value (NPV) will be calculated, representing the profitability of the investment according to the following equation:

$$NPV = \sum_{t}^{n} \frac{CF_t}{(1-i)^t} \quad (5)$$

Where:

- CF_t is the value of the cash flow in period "t". This can be estimated by the following equation:
  $CF_t = Rev - Exp$ (6)
- Rev are the revenues for period.
- Exp are the expenses for period.
- t is the nth period of money investment time.
- n is the number of periods.
- i is the cost of capital.

If the NPV value is positive, it is expected that the investor will have a return greater than his cost of capital, i.e., the investment is profitable. The reverse is true when NPV is negative.

Another economic indicator of projects is Payback, which corresponds to the period in which the project's accumulated net profits are at least equivalent to the investment and is calculated as the total investment value divided by the average cashflow time result. The Internal Rate of Return (IRR) indicates the percentage of project profitability and represents the rate of return of projects (Buarque, 1984).

The situation without BNDES financing was considered to calculate payback and IRR. The amount of the payback resulted in 1 year, 6 months and 4 days for the investor to be able to return the initial amount invested in the vessel.

2.5 PRELIMINARY SHIP DESIGN

The preliminary ship design was based on specific conditions to meet the needs and first design decisions, being presented in a summarized and structured manner according to the next subsections.

2.5 (a) Hull Design

The shape of the hull must be designed from the main dimensions and physical characteristics defined in the previous step.

This shape is designed in accordance with the shipowner's requirements (i.e., cargo space) and physical characteristics (i.e., main dimensions). This also involves decisions regarding the location of the superstructure, internal and external cargo space and stern shape, which strongly depends on the type of propulsive system. So the design must keep in mind the type of propulsive system without the need for details. Thus, we suggest analysing the hull shape of vessels with similar dimensions and purposes. A study to analyse the need for a bulbous bow must also be made and can be conducted with the methodology proposed by (Watson, 1998).

The result of the hull design step is a three-dimensional model, for which one of the various 3D modelling tools (e.g., SolidWorks, Rhinoceros, AutoCAD) can be used along with the line plan. In this study, we use Rhinoceros 3D (Rhinoceros, 2019) for the 3D modelling, which is based on NURBS technology for representing 3D curves and surfaces.

2.5 (b) Compartment Layout Definition

The preliminary structural elements and arrangements such as side plating, inner plating, bottom and inner bottom must be defined following the rules determined by the classification societies (e.g., American Bureau of Shipping (ABS), Bureau Veritas, Det Norske Veritas). In this study, ABS standards were followed (ABS, 2019).

An important dimension measured at this stage of the design is the freeboard, which establishes the maximum level of hull immersion so that the vessel maintains a minimum reserve of buoyancy. To define it, the regulations of the International Convention on Load Lines (IMO, 2005) were followed.

To perform this step, we suggest using Maxsurf software (Maxsurf, 2019), which is used to develop optimized vessel designs with integrated naval architecture tools. At the end of this step, there will be a preliminary compartmentalization of the vessel and 3D model of the hull, so that further analysis can be performed.

2.5 (c) Stability Analysis

At this design step, an analysis is made the intact and damaged vessel stability, following the criteria set by the International Maritime Organization (IMO, 1993) and Annex 1 of MARPOL (MARPOL, 2008). These analyses are made for different loading conditions and compartment failure, and all must have good stability (i.e., metacentric height and maximum angle GZ should not be less than 1,5m and 25deg, respectively).

For this purpose, we suggest Maxsurf Stability, an extension software for stability analysis that integrates the criteria for the intact and damaged stability. Maxsurf makes it possible to position all the ship's compartments and tanks, loading and damaging them according to each analysed condition.

At the end of this step, we will have the vessel's stability curves (GZ curves, i.e., graphical representation of the ship's transverse stability, that plots the righting lever between the heel angle) for the loading conditions proposed by the classification society. The vessel must meet the criteria to ensure its stability and the safety of the cargo and the crew.

2.5 (d) Propeller System

To dimension the propeller system, follow these steps:

- Advanced Resistance Calculation: use Maxsurf Resistance software, a tool for estimating the vessel's resistance and power requirements by using different methods (e.g., Holtrop, van Oortmerssen, Series 60, Slender Body). Choosing the appropriate method will depend on the main dimensions of the vessel. For further information about these methods see (Bentley Systems, 2017). The total resistance and the required power will be the result of this calculation;

- Propeller Size: bearing in mind the propulsion type that will be used on the vessel, in this step the propeller type is defined based on the vessel's operating characteristics, feasibility and suiting its priorities (e.g., pulling force requires Kaplan-type propellers, speed requires B-series propellers). The most appropriate approach will vary according to the propeller chosen. Estimates should be made (e.g., blade number, delivered horsepower) for sizing commencement and throughout various analyses and comparisons with other propellers to obtain final optimized propeller data (i.e., diameter, disc area ratio, number of blades, propeller pitch, revolutions, DHP, propulsive efficiency). For further information, see (Bernitsas, Ray and Kinley, 1981; Passos, 2013; Mendes, 2015);

- Engine Selection: After obtaining the required power, the next step is to choose of the engine from marine engine manufacturers (e.g., SCANIA, Caterpilar, Yanmar, Sole Diesel). At the end of this step, we will have the engine data (i.e., rpm, power, equipment weight);

- Steering System Size: follow the procedures proposed by SNAME (SNAME, 1990), where the type of rudder is chosen and the longitudinal area of the rudder is calculated. To calculate the system torque, follow the classification society regulations for the ship. This study followed the calculations proposed by ABS (ABS, 2019). With the calculated torque, a suitable rudder machine is chosen from manufacturer catalogues (e.g., Vision Marine, Dtecto, Bonfiglioli).

2.5 (e) Structural Design

In this step, what calculated is the section modulus of all structural elements (i.e., Bottom Girder and Transverses, longitudinal and transversal side frames; peak frames forepeak and aftpeak; side web frames; side stringers; bulkheads, deep tanks and superstructure stiffeners), following the ABS (ABS, 2019) requirements. First, the wave bending moment and the wave shear force are calculated and expressed in graphics. Then, the thickness of the plates and section modules of the structural profiles are calculated. In general, calculations are made using the main dimensions and other parameters defined by the ABS.

After defining all the elements for the amidship, this configuration was assumed along the entire hull to apply the forces and acting moments, resulting in bending moment and shear force curves that were within the limit of the structural envelopes calculated according to the ABS (ABS, 2019).

Finally, the momentum and stress envelopes acting on the vessel are obtained. The SMath Studio tool (SMath Studio, 2006), a mathematical program with an integrated computational algebra system, is used for all the structural calculation. Follow the regulations of the classification societies for the ship. In this study, the calculations proposed by ABS (ABS, 2019) were used.

2.5 (f) General Arrangement

The definition of the deck equipment and the arrangement of the accommodation and cargo spaces are outlined at this stage of the project. The arrangement is based on similar vessels and the equipment definition follows the classification societies' rules, as well as those of national (e.g., for Brazil (DPC, 2005a) and international organizations (ABS, 2019).

Due to the limitations and difficulties of operation at the port of FN, a crane was selected, and a bow thruster was designed. The procedure proposed by (Journée and Massie, 2001; American Petroleum Institute and API, 2005) was followed to calculate the current, wind and wave forces in the region.

A complete and detailed arrangement must result from this step, thereby locating all the equipment, cargo hold and accommodation space.

In this step, the lightship weight was also estimated, which was made based in the structural elements of the ship defined above. The weight curve was generated from the conversion of the area curve obtained by Maxsurf (Maxsurf, 2019). The superstructure and selected equipment were added to form the final curve for estimating the lightship weight.

2.5 (g) Seakeeping Analysis

A seakeeping analysis becomes necessary when the route of the vessel is under extreme sea conditions. This study assesses the probability of a certain phenomenon occurring that may affect the safety of the structure, crew and cargo (e.g., propeller emergence, trapped water, slamming, deck submergence). The hull was simulated in the Ansys software Aqwa extension for the vessel's seakeeping analysis (ANSYS, 2017). To obtain a reasonable estimation, the calculations must follow regulations and the probability results must be below the minimum criteria (i.e., the event occurrence of slamming, propeller emergence and water on deck must not exceed 1%, 5% and 5%, respectively) (ITTC, 2014; Cabrera and Medina, 2016).

3. RESULTS

In this section, the proposed approach will be applied in the case of FN.

3.1 DATA GATHERING

3.1 (a) Data Gathering and Database Construction

Following the approach, the resulting database covered 102 vessels. Some of the similar vessels found in the database are shown in Table 2.

In the database, it was possible to notice a wide range of Cb, opening the possibility for barge-type vessels, but all vessels that fit within the definition of barge from NORMAM 01 (DPC, 2005a) were removed.

3.1 (b) Data Processing

The criteria to remove outliers, the number of vessels removed from the database and the correlation index obtained are presented in Table 3.

The power prediction method regression was made considering the service speed (Vs) due to the best correlation index found (i.e., 0.75). The index found with the other ship parameters varied within the range of 0.2 to 0.3.

Table 2: Database

Name	Nationality	LOA (m)	Lpp (m)	Beam (m)	Draught (m)	Depth (m)	Vs (kts)	DWT (ton)	Fn	Cb	MCR (kW)	Displacement (ton)	Gross Tonnage
Wilja	Holanda	37.97	30.09	6.51	2.72	3.95	7.50	275	0.20	0.78	150.0	537.96	133.52
Roberta	Holanda	37.96	34.74	7.33	2.63	2.91	9.00	370	0.24	0.67	325.0	459.65	248.00
Jura	Holanda	37.61	33.69	6.61	2.50	4.01	8.50	250	0.23	0.71	150.0	450.60	197.00
Setas	Holanda	37.24	35.31	6.54	2.40	2.65	8.50	250	0.23	0.70	150.0	421.68	199.00
Scan Viking	Noruega	36.00	19.08	7.00	3.90	4.24	7.10	40	0.19	0.79	157.5	422.38	317.00
Herm	Holanda	36.00	34.20	6.90	2.60	4.18	9.00	295	0.25	0.65	145.4	409.68	211.00
Anda	Holanda	36.00	34.20	6.00	2.00	3.64	7.10	345	0.19	0.79	124.1	332.73	195.00
Globe	Holanda	35.66	32.89	6.48	2.37	3.93	8.50	250	0.23	0.69	120.0	386.31	200.00
Fiat	Holanda	35.50	33.58	6.44	2.28	2.35	8.00	245	0.22	0.73	135.0	368.45	197.00
SN3	Estônia	34.00	26.59	7.00	2.90	4.24	9.50	108.25	0.27	0.61	125.0	335.16	170.00
Mary	Holanda	33.99	28.48	6.10	2.28	2.49	7.50	229	0.21	0.75	120.0	365.68	174.00
Hollandia	Holanda	33.42	30.94	6.28	2.10	3.81	8.90	200	0.25	0.64	120.0	286.85	163.00

Table 3: Data processing criteria

Correlating Functions	Criteria to remove outliers	Number of vessels removed	Correlation index
LOA x B	Slender ships, LOA/B > 6	31	0.7159
MCR x Vs		0	0.7535
DWT x L	L/DWT > 0.2	11	0.7429
CB x DWT	Limiting factor: length of vessel (FN port restrictions) and outliers	49	0.6142
L x D	L/D > 12 and L/D < 6	21	0.7180
B x D		0	0.7658
D x T	D/T > 2	34	0.6028

B x T	B/T < 2 and B/T > 3	33	0.6635
L x T	T > 4 and L/T < 13	35	0.6686
DWT x D	D < 3 and D > 6	26	0.6562
Vs x Fn		0	0.6856

3.2 OPTIMIZATION MODEL

The parameter estimates, assumptions and references for the model are given in Table 1.

From survey of estimated costs of an old vessel it was possible to find the depreciation and a proportionality constant for the calculations of cost of acquisition per ton that resulted in the following values:

- Price estimated for a new 500t of DWT vessel: US$ 1.91 M
- Price per DWT for a new vessel: US$ 3.82 K/ton;
- Price per DWT for an old vessel: US$ 488/ton;
- Price estimated for an old 500t of DWT vessel: US$ 244 K.

The depreciation was estimated at:

$$\%Depr = 8.58\%\ per\ year$$

The crew cost was estimated at 55.5% of total operational cost (Počuča, 2006; Maritime Executive, 2011; Lloyd's List, 2018; Shipcosts, 2019), the crew being a captain, a chief engineer, two deck officers, an engineer officer and a cook.

Ship insurance was estimated as being 1% of the total acquisition cost of a new vessel with 500 tons of deadweight. It was considered that the sale and negotiation would be the responsibility of the crew, so that the cost attached to the administration was insignificant and the structure of the AFN could be used for administrative efforts such as accounting and advertising. The costs of maintenance, repairs and materials were calculated so that their share would be 25% and 10% of the operational cost, respectively. The estimated values based on operating cost are shown below:

- Crew: US$ 126 K (56%);
- Maintenance and repairs: US$ 56.3 K (25%);
- Materials: US$ 22.5 K (10%);
- Insurance: US$ 20.3 K (9%).

The total operational cost was US$ 225 K for a vessel with 500 tons of deadweight. The following operational cost per ton of deadweight was calculated as US$ 412.95/ton. Table 1 shows the functions and cost considerations.

3.3 COMPUTATIONAL MODELLING AND SIMULATION

The results obtained from the simulation of the mathematical model are shown in Table 4. These results are consistent, as the main dimensions meet the limitations of the FN port (i.e., 50m length) at a plausible optimal cost for a vessel of this size (US$ 8.22 M), whole dimensions are similar to those of a platform supply vessel (PSV) or a tug.

Table 4: Mathematical model results

Length	35.55	m
Beam	7.14	m
Depth	4.00	m
Draught	2.62	m
Block Coefficient	0.67	
Displacement	453.18	t
DWT	266.45	t
Service Speed	10	m/s
Froude Number	0.28	
Power	367.59	kW
Fuel Weight	4.41	Ton
Lubricant Oil Weight	0.01	Ton
Water Weight	1.13	Ton
Vessel Size	6.45	Ton/trip
Vessel Load	260	Ton
Sea time	60	Hours
Loading time in Recife port	13	Hours
Unloading time in FN port	13	Hours
Number of trips	30	trip/year
Loading cost in Recife	129.30	US$/trip
Unloading cost in FN	229.69	US$/trip
Fuel cost	4.96 K	US$/trip
Lubricant oil cost	1.23	US$/trip

Operational cost	110 K	US$/year
Consumables cost	1.78 K	US$/trip
Acquisition cost	1.02 M	US$
Total cost	9.09 M	US$/25 years
Fleet	1	vessel

3.4 ECONOMIC FEASIBILITY ANALYSIS

The data on financing the vessel was estimated according to BNDES (BNDES, 2017). This financing has benefits that follow the modality of the constant amortization system, with the following values:

- Interest rate: 6% per year.
- Financing: 90% of the acquisition cost.
- Grace period: up to 4 years.
- Amortization period: 20 years.

The calculated cost and revenue data were structured in a cash flow and thus the NPV was calculated. The cash flow is structured as shown in Table 5.

According to (Gaspar, 2013), it is a challenge to incorporate all variables and expectations within the value of a system, since the future is uncertain. The ship's value cannot be considered purely monetary. It needs to be robust, having the ability to incorporate the risks faced, delivering a positive and relevant final value to investors. It is necessary to maximize the values in a range of risk situations to reduce the maximum possible losses, although reducing the reward.

The cash flow obtained is shown in Figure 3. We assumed that the entire investment was spent at the beginning of the first year, and that the ship took 2 years to be constructed (columns 1 and 2 in Figure 3). Therefore, the columns 3 to 27 represent revenues for 25 years of operation after construction. The negative flow between years 0 and 1 indicates the initial investment of AFN, which corresponds to 10% of the acquisition cost of the vessel. From year 2 onwards, the flow is positive, decreasing over the following years due to the increase in costs due to inflation in Brazil. The assumed inflation rate was 5.93% per year. It was considered that the value of freight would not rise along with inflation (perspective of a conservative investor).

Nevertheless, the NPV is presented as a high and positive value (i.e., US$ 15.4 M). This means that investing proves to be economically feasible for AFN. The average annual cash flow (i.e., US$ 1.76 M) represents the amount that AFN would save per year on freight (i.e., 7.9% of FN's GDP). The savings in 25 years of life would be US$ 47.6 M.

The IRR had a result of 115% in relation to cash flow, being higher than the value considered for TMA (i.e., 15%). Thus, it is concluded that the investment is economically attractive.

Table 5: Cash flow structure

	Year zero	Subsequent years
Revenues	Financing = 90% of acquisition cost	Assumed constant over the years = US$ 2.87 M
Expenses	Equity = 10% of acquisition cost	Interest rate= 6% of outstanding balance in previous year
		Amortization = constant amount equal to financing divided by number of instalments = US$ 45.8 K
		Insurance = according to the approach (Section 3.3) = US$ 10.2 K
		Operational cost = according to the approach (Section 3.3) = US$ 225 K
		Profit tax = 15% of profit = US$ 429 K

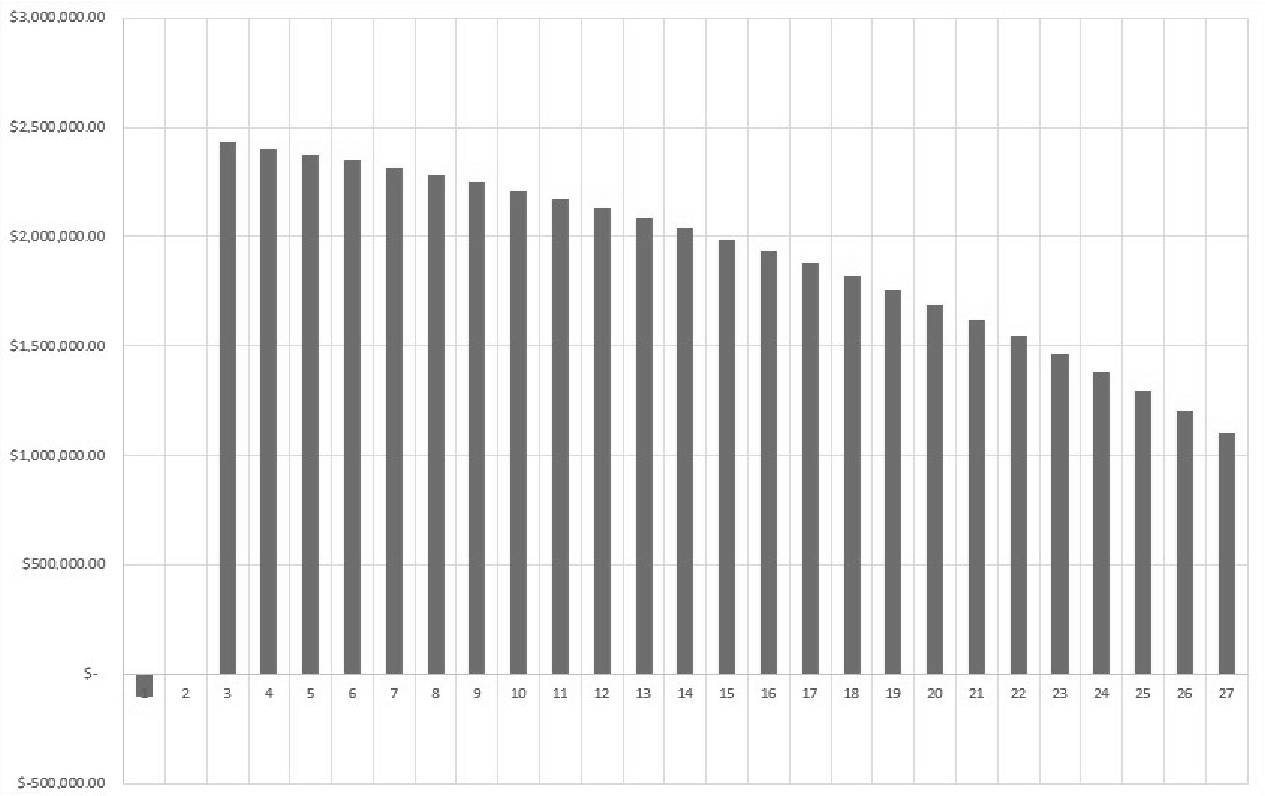

Figure 3: Cash flow for 2 years construction (columns 1 and 2) and 25 years operation (columns 3 to 27).

3.5 PRELIMINARY SHIP DESIGN

This section presents the results of the ship design stages of a specialized general cargo vessel applied to the case of Fernando de Noronha.

3.5 (a) Hull Design

The shape of the hull shape along the length is similar to that of cargo vessels, as shown in Figure 4. Despite making it difficult and expensive to build, a bulbous bow has been designed to significantly improve the vessel's performance by more than 10% at service speed, using the proposed approach (Schneekluth and Bertram, 1998; Watson, 1998). Although there is an increase in the construction cost (fixed cost), the bulbous bow can help to reduce a ship's resistance and thus to save the fuel consumption by up to 15% over the vessel's life (Liu *et al.*, 2014), thereby recovering the ship's construction costs.

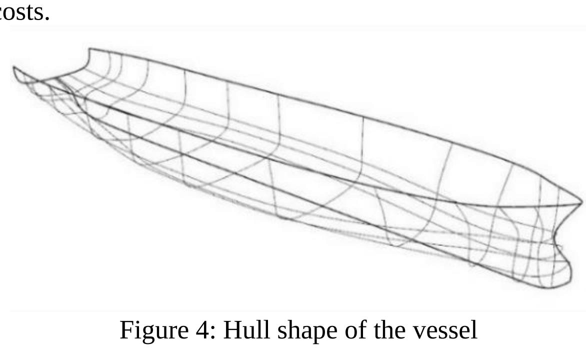

Figure 4: Hull shape of the vessel

3.5 (b) Compartmentalization

A double bottom is not required for vessels with LOA < 90 m, as long as this does not compromise structural integrity when subject to stresses and moments (ABS, 2019). The minimum value of the freeboard was 0.4m, resulting in a maximum draught of 3.6m. This result meets the vessel's main dimensions from the optimization model.

After defining the position of forward and aft peak, the vessel will have 3 cargo holds and a forward engine room, as shown in Figure 5.

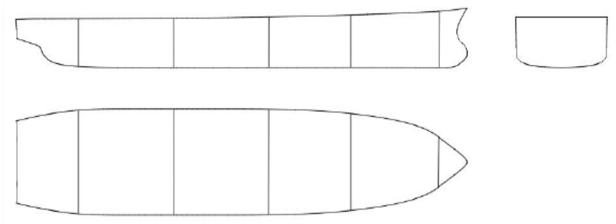

Figure 5: Preliminary compartmentation

3.5 (c) Stability Analysis

The vessel presented intact stability under all conditions analysed required by norm (i.e., 100% loaded with 100% and 10% consumables). As shown in Figure 6, both conditions showed good stability (i.e., metacentric height and maximum angle GZ are greater than 1,5m and 25deg, respectively, as shown in section 2.5 (c)).

The light condition (i.e., 50% loaded with 100% and 10% consumables) was analysed and showed that for the vessel to be stable in this condition it needed to carry ballast to reach the design draught (i.e., 2.62m). This condition is not economically viable because the ballast load does not add value. Therefore, this indicates the vessel should always be loaded (i.e., with supplies going to FN and garbage on return).

As to damage, the conditions of each damaged compartment were analysed and all showed, good stability (i.e., range of positive stability and residual righting lever not less than 20deg and 0,1m, respectively). Conditions with two damaged cargo compartments were also analysed, which showed good stability, except in the case where cargo tanks 1 and 2 were damaged. To achieve stability, it was necessary to add ballast near the bow.

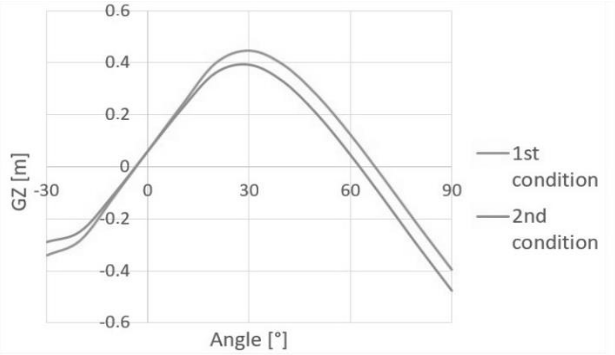

Figure 6: GZ curves

3.5 (d) Propeller System

The propulsion system design considers the resistance of the hull to incident waves. The approach used was applied in 5 propellers of 4 blades and different expanded area ratios. The optimum propeller shown in Figure 7, has the following characteristics:

- Diameter: 1.4 m;
- Area ratio: 1.0;
- Efficiency: 0.46;
- DHP: 309 kW;
- Thrust: 40 kN

With the propeller data, the brake horsepower was estimated and a 470 kW engine (MAN, 2019) and a reduction gear with a 5 to 1 ratio (Tramontini, 2019) was chosen.

Figure 7: Optimal propeller geometry

3.5 (e) Structural Design

The thickness of the hull plating (e.g., bottom and side shell) and the reinforcement section modules (e.g., bottom girder, transverses, longitudinal side frames and peak frames) were calculated and resulting in the preliminary structural arrangement of the midsection shown in Figure 8. After carrying out the momentum and stress envelopes analysis, the vessel presented structural integrity due to the structural arrangement determined.

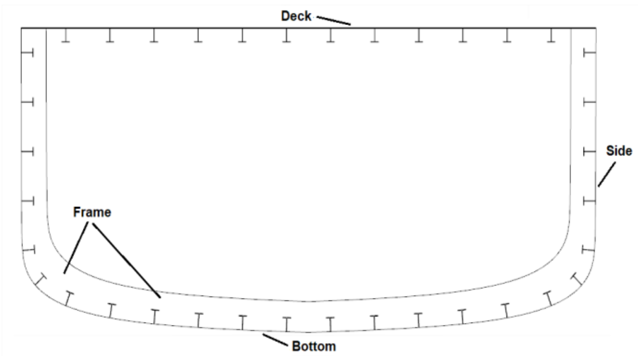

Figure 8: Vessel structural arrangement

3.5 (f) General Arrangement

Having defined the deck equipment, engine room and consumable tanks, the general arrangement shown in Figure 9. was defined. A crane with 10 m radius range was selected (Macgregor, 2019) and a bow thruster was designed with 350 kgf was chosen (Side-Power, 2019).

The estimated lightship weight after defining the items and equipment that made up the general arrangement was approximately 150 tons. For more details on general arrangement of cargo ships see (Tapscott, 1980) and for Figure 9 in larger size and high resolution see (Santos, 2021).

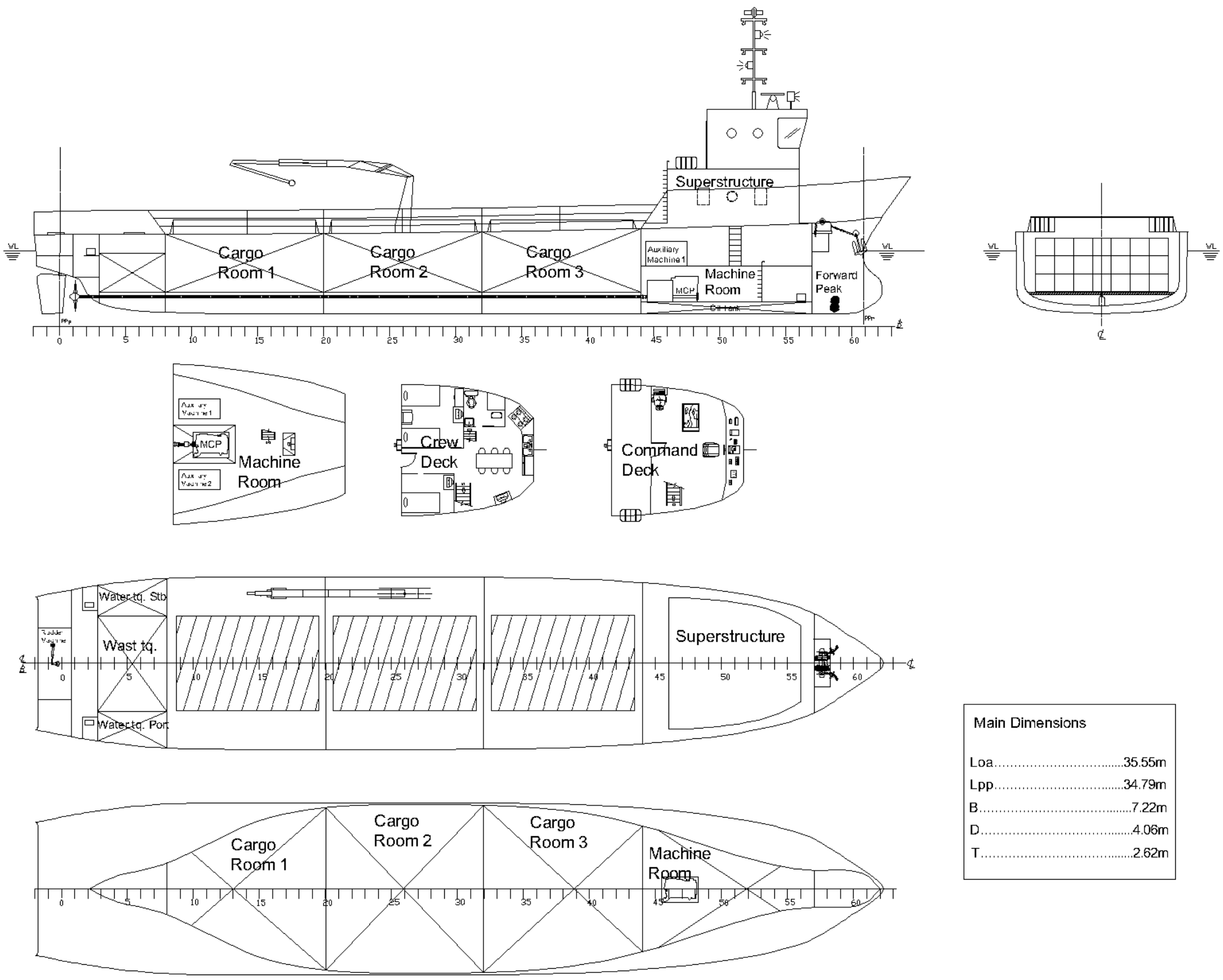

Figure 9: General Arrangement

3.5 (g) Seakeeping Analysis

Under critical sea conditions (i.e., waves > 2.5m), the probability of occurrence of seakeeping phenomena (e.g., slamming, water on deck) was above what is considered acceptable by norm (ITTC, 2014). To reduce the probability to an acceptable level and ensure safety on board, the vessel must operate at half its service life (i.e., 5 knots).

Critical sea conditions occur in the months of December to March (Raul, 2018). Our model is robust against uncertainties in the duration of the trip since we conservatively assumed only 30 round trips per year and that any trip can last up to 12 days. A round trip in normal conditions would take 6 days, and a round trip in critical conditions would take 9 days (i.e., assuming the vessel operates at half its service life), so there would still be 6 days for each round trip as a safety margin for delays due to critical conditions.

4. DISCUSSION

Since the current literature is mostly focused on the design of large cargo vessels, the approach presented here seeks to contribute to the replication of the steps for the design of any small cargo vessel for a given purpose (i.e., specialized), in a more efficient and safe way for the environment and society.

Regarding the case of FN, the designed vessel can be classified as a cargo ship. Its characteristics are similar to those of tugs and PSVs. The main regulation and laws for operating this type of vessel in Brazil are from the Brazilian navy (DPC, 2003b, 2003a, 2005a, 2005c, 2005b). For this vessel, a pilot service is not compulsory, according to NORMAM-12 (DPC, 2011), since its gross tonnage is less than 2000.

In addition to being a vessel designed to sea conditions and seeking to meet the island’s demand and draught limitations, it was realized that the main difference and advantage against the adapted vessels is the travel time from Recife to FN. The exisitng vessels take around 3 days or more on the route (Marinho, 2017, 2018) while our proposed vessel would take less than 2 full days for the same route, transporting the resources needed for island with more efficiency.

The main shipyards in Brazil with the capacity to construct a vessel of this size without difficulty (e.g., obtaining and forming the hull plates) are: INACE (Fortaleza, CE), Detroit Brazil (Itajaí, SC), Rio Maguarí (Belém, PA) and Erin (Manaus, AM). For a vessel of this size, the rudder, a simple reinforced plate, is usually manufactured in the shipyard itself. This meets the minimum area requirements established by the classification society, and the vessel weight and speed do not justify the construction of a hydrodynamic profile. However, the manufacture of a propeller is not economically viable, so it is common to find manufacturers that provide standardized propellers in sizes and types that are compatible with the project.

This vessel could bring considerable savings to AFN, which in turn could be used to invest in other areas for improving the quality of life and conservation of nature in the island. In this sense, this work brings a socio-environmental contribution. As it is a vessel specially designed to operate on the route Recife-FN, the chance of shipwrecks and marine pollution are reduced, unlike other vessels that operate in FN, which have already suffered accidents at sea. Also, it would have less chances of accidents and pollution on the island's coast, thus contributing to the sustainability.

The IRR of the investment was 115% which may seem too high. However, note that the IRR here is a measure of potential return and not guaranteed return. In general, investments with high potential return are associated with high risks, as is the case here. There are many risks in this investment which were not detailed in this work, e.g.: cabotage sector is quite unstable in Brazil (Navios, 2018, 2020; Notícias, 2019); the real return depends on commodities (e.g., diesel) with high volatility; high risk of cargo theft by the crew; FN already has a monopoly of local investors that may potentially cause difficulties and delays to new investors in the process of legalizing the vessel for local operation; FN is an environmental protected area, so any accident that causes pollution may lead to expensive fines; navigation in a route that already caused many ships to sink. A detailed risk assessment was not conducted in this work. We acknowledge this as a limitation and propose it for future works. Also, investors should be aware that this business requires continuous administration, planning and control of operations over the years.

We also concede that discussions about procurement were not carried out as part of the design process (concept exploration and risk assessment). This is another limitation that requires future studies. Finally, another proposal for future works is to integrate in this model the additional profits from garbage transportation on the return trip. For a pessimistic economic analysis, we did not consider these in this work.

5. CONCLUSIONS

The approach offers a significant contribution to the state of art in the preliminary design of small vessels that specialize in a single route. It can be used by students and practitioners as guidance on how to design an efficient and safe vessel in a structured way.

The results led to a ship design considered to be effective and safe, that could be produced and improve the quality of life on the island. An economic feasibility analysis showed that it is a viable investment for the AFN and the savings could be used in other sectors of public management (e.g., sanitation, education and tourism), contributing in a sustainable way to the life of the island's community and environment. Three issues are proposed as requiring further study: risk assessment, discussion about procurement and additional revenue from garbage transportation on the vessel return to Recife.

6. ACKNOWLEDGEMENTS

The authors thank Gustavo Roque for the idea that started this project and Hugo Machado, the captain of the Mr. NR vessel, for providing us some information that was useful for the model parameterization.

The authors would also like to thank the anonymous reviewers for their extensive and detailed comments, which have greatly enhanced the coherence and accuracy of the paper.

We are also grateful to the coordination unit of the naval architecture course of the Federal University of Pernambuco for providing the software and hardware to carry out this work.

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