Cruise Ship Itinerary Design

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ABSTRACT: Cruise tourism is a fast-growing industry worth more than $150 billion dollars. One of the key factors of success in this industry is the ability to create great value itineraries, capable of attracting tourists meanwhile maximizing the total profit for the cruise shipping company. To do this, a route must be carefully selected, combining a maximization of the total attraction value of the itinerary, given by the destinations and attractions included, with the minimization of the total cost of the itinerary. The objective of this paper is to develop an optimization model resorting to the mixed integer programming technique and use the CPLEX solver to find optimum cruise itineraries. An application is made to evaluate possible new optimal cruise itineraries along the coast of the Iberian Peninsula. The model chosen in this paper calculates the cost and the revenue of the itinerary separately, using a cost structure based on the size of the ship and the duration of the itinerary, and a revenue structure based on the month of the year and the ports selected. The results showed an opportunity for new itineraries in the Iberian Peninsula region, calling at ports which are not traditionally famous for cruising activities. In particular, cruise ports located at Morocco showed a competitive advantage in comparison with the cruise ports located at the north Iberian Peninsula, such as Leixões and A Coruña, due to the more attractive weather.

1 INTRODUCTION

In 2018 approximately 28.5 million passengers traveled in cruise ships and from that total, about 50% came from North America, 24% from Western Europe and 15% from Asia (CLIA, 2018). At the same year, Caribe and Mediterranean were the two most important destinations, accounting respectively for 35.0%, and 16.7% of the global cruise ship deployment, measured in bed days (MedCruise, 2018). The cruise industry is growing fast: between 2008 and 2018 the average annual growth rate was 5.7%, employing in 2018 almost 1.2 million persons which earned a total of $50.2 billion in wages (CLIA, 2018). The current Covid-19 pandemic has caused a complete halt to this important industry, but this should certainly be a temporary setback, with a progressive recovery throughout subsequent years.

This industry is constituted by an oligopoly market, being that the four largest companies combined own more than 80% of the global fleet (Pallis, 2015). These large companies use a strategy of multiple brands (for instance, Carnival Corporation owns Carnival Cruise Lines, Princess Cruises, Holland America Line and Costa), focusing each company in only one segment of the market, creating the impression that there is plenty of competition between companies. The cruise itineraries sold are classified in four categories: contemporary, premium, luxury and special. Contemporary itineraries are the most popular type of cruising, with large cruise ships offering a lot of onboard activities for a great value (Pallis, 2015).

Given the seasonality characteristic of tourism demand, cruise operators reposition their fleets around the globe to take advantage of regions with high demand for cruising during the whole year (Rodrique et al., 2012). One good example of this practice is the movement of ships between the Caribbean Sea and the Mediterranean Sea. During Summer, the ships are deployed in the Mediterranean Sea, whereas during Winter, the demand for cruise voyages in the Mediterranean Sea decreases and the cruise ships are repositioned to the Caribbean Sea. Nowadays, cruise liners are aiming at the Brazilian, Australian, and Chinese markets as they are considered markets with high growth potential (CLIA, 2017; Dowling, 2011). Australia and Brazil both have an extensive coastline, a more stable weather throughout the year and are in the south hemisphere. Additionally, because both countries are in the south hemisphere, they are good alternative places to reposition the global fleet during the Winter in the north hemisphere. In 2018, China, Australia and Brazil ranked respectively 2nd, 5th and 10th in terms of the volume of passengers per country (CLIA, 2018). Only in 2018, on average a cruise passenger spent $375.97 at the homeport and $100.79 at the other ports, resulting in a total of $10.7 billion spent at homeport and $9.1 billion spent at the other ports (CLIA, 2018). The reason why expenditures at homeports are higher is because many tourists travelling to these cities to start their cruise extend the stay for some days before or after the cruise. Although homeports earn more money, it is also true that they must have a good infrastructure, capable of receiving large cruise ships, and with a good transportation connectivity (Niavis et al., 2016). In regions of beautiful natural landscapes and beaches but with a poor infrastructure, such as the Caribbean islands, cruise companies are constructing expensive dedicated terminals in privately secured areas, to satisfy the cruisers desires and expectations.

Rodrique et al., (2012) argues that the cruise industry differentiates from any other traveling industry because it sells itineraries rather than destinations. The itinerary comprises a whole package with destinations and activities previously determined. This fact means that the demand for this service is given by the attractiveness of the itinerary as a whole, showing that when designing an itinerary, factors such as time at destinations, distance between destinations and traveling speed must be taken into consideration. Historically, this problem, called cruise ship itinerary design, has not received so much attention since cruise companies never found difficulties in filling their ships, especially at the Caribbean Sea. However, this scenario is changing recently, given that the Caribbean Sea market is reaching a saturation point, many cities in Europe are experiencing problems with the cruise industry and new markets are arising. These factors lead to an urgency in finding new possible itineraries across the globe.

Cruise ship itinerary design problem is a type of vehicle routing problem, which is one field of operations research. This field
has developed considerably, supported by cheaper and more accessible computers to solve at least some of the vehicle routing problems. Examples of optimization software’s which can be used in a simple computer are CPLEX and GUROBI.

The objectives of this paper are to understand how cruise ship itineraries are designed, identifying which are the most important parameters in the selection of ports of call, including port attractiveness, location within a geographic region, nautical limitations, and weather conditions, among others. Using this knowledge, an algorithm for optimizing cruise itineraries is to be developed, selecting the ports of call of the itinerary, time of arrival and time of departure at each port and the ship’s speed in each leg of the itinerary. The optimum itinerary is to be determined so as to maximize the net profit per voyage for the cruise shipping company given a list of possible ports of call, for a given geographic region, specific ship size, duration of the voyage, season of the year. A commercial software will be used to implement the algorithm and test its performance in two case studies, one in the Atlantic coast of the Iberian Peninsula and the other in the Brazilian coast.

This remainder of this paper is organized in five sections. Section 2 is a literature review about cruise shipping industry, focusing on four main topics which are important to the knowledge of the shipping industry in general and to the itinerary design process: ports of call and destinations, cruise passengers, tickets price and revenue management and, cruise ship itinerary design. Section 3 details the methodology applied, giving an introduction about linear and integer programming, defining the traveling salesman problem, the vehicle routing problem, and the cruise ship itinerary problem. Section 4 presents the formulation used in this paper, showing all assumptions and equations considered. Section 5 shows the numerical results obtained in the case studies, presenting the optimal itineraries obtained, its cost and revenue structure, and analyses of the results. Finally, section 6 indicates the main conclusions of this study and provides a set of recommendations for further works in this field of study.

2 LITERATURE REVIEW

Most of the research about the cruise industry was published in recent years, focusing on passengers’ behavior and expectations, impacts of cruise tourism, and growth and development of cruise tourism (Wondirad, 2019). In this section, a literature review about the cruise ship itinerary design problem is conducted, giving a detailed discussion about which are the most important variables, restrictions and assumptions used to model the problem. Also, details about how these models are solved and which information can be obtained from it are shown in this section. The first topic covers publications which are concerned in evaluating how cities and destinations are affected by cruise ship activities, analyzing the economic, social, and environmental impacts on the ports or cities. The second topic focus on the passengers, trying to characterize the cruise passenger profile, including their preferences, motivations, and satisfactions. The third topic studies how to determine cabin prices and marketing strategies to return maximum revenue as possible. Finally, the last topic investigates the models and algorithms developed for the cruise ship itinerary design problem.

2.1 Ports ofCall and Destinations

Ports of call are a crucial part of the itinerary planning since passengers use them constantly to embark and disembark and modern cruise ships requires an infrastructure that not all ports may provide. They are the link between cruise ships and destinations. Despite the cruise industry fast growth, fostering cruise activity does not mean that a city or port will have direct economic benefits from it. As pointed by London et al. (2014), this relation between cruise line, city and ports is very complex. Cruise lines can choose to call or not into the destination, ports may create bureaucracy and barriers to the cruise ships operation since it may compromise the core business of the port, commercial ships, and local communities or local government may express dissatisfaction and complain about cruise tourists. All these factors lead to a situation where the success of cruising activities at a destination depends on the cooperation of the three parties.

Wang et al. (2014) sent a questionnaire to cruise lines, asking which are the most important factors when choosing a port of call. According to the answers, touristic attractions are the most important element in a destination, followed by port connectivity and by distance of main attractions from the cruise terminal. This later element is important to a cruise line because it means ships calling can have a lower call time without compromising the utility of the call, as perceived by passengers. Gouveia et al. (2019) estimated the total economic value of cruise tourism at the port of Funchal in €47.2 million, separating it in passenger expenditure (€30 million), crew member’s expenditures (€8.3 million) and cruise lines expenditures (€8.8 million). With the objective to identify which factor makes ports potential homeports, Niavis et al. (2016) proposed an empirical model, relying on data of Mediterranean ports. The factors analyzed were divided into two categories, similar to what McCalla (1998) proposed: ports’ characteristics and hinterlands’ characteristics. The variables used to measure the port characteristics are port efficiency, type of management of the cruise terminal, berth length and port connectivity. The variables used to measure the hinterland characteristics are air connectivity index, capacity of tourist infrastructure and gross domestic product per capita. Results showed that efficient ports, private managed, with long quays (more than 350 meters in length) and directly cooperating with one cruise line, are more likely to become homeports. Pallis (2015) published a state-of-the-art paper presenting a review, among other topics, about cruise ports characteristics, performance, and competition. In the paper, a deeper analysis is made about location and growth of cruise ports, type of management in different regions, effects of seasonality, performance, competition and cooperation, economic and environmental impacts, perception of value for the local community.

2.2 Cruise Passengers

Studies about passengers are one of the most researched areas of the cruise industry. These publications focus on creating or validating hypothesis about the passengers’ profile, expectations, and motivations. The common approach for this type of study is to conduct interviews and questionnaires. Since culture, age and economical position plays an important role on the people’s behavior and expectations, it is expected that studies will vary a lot their results, depending on the persons interviewed. Qu et al. (1999) interviewed Hong Kong cruise travelers’, investigating motivation factors, satisfaction
attributes and the cruiser’s profile. Xie et al. (2012) investigated motivations factors for cruisers and potential cruisers based on reviews randomly selected from a worldwide cruise company website. Whyte (2018) conducted interviews in Vancouver using open-ended questions to assess the onboard and onshore attributes that contributes to the cruise tourists’ perceptions of the cruise destination, in a qualitative analysis. Petrick (2011) examined the relation between reputation of a cruising company and the passenger willingness to pay by interviewing cruise passengers. Sun et al. (2019) attempted to evaluate the cruiser experience with shore excursions or activities of a cruise ship departing from Shanghai to a China-Japan route, using a questionnaire divided in three parts: importance of onshore activities, cruiser satisfaction with these activities and demographic information from cruisers. Mahadevan et al. (2017) made a step further, studying the relationship between cruiser willingness to pay and different attributes of a cruise voyage.

2.3 Tickets Price and Revenue Management

Cruise companies most important sources of revenue are tickets, onboard activities, and excursion packages. Despite nowadays onboard activities and excursions are becoming more important in terms of percentage of the total revenue, tickets are still the major source of revenue for those companies. The ticket price is crucial to the success of an itinerary: if on one hand ticket price affects the demand for a cruise voyage, on the other hand tickets are sold with antecedence of months before the voyage, giving to the company a reasonable knowledge about the occupancy of the ship. Also, in a capital-intensive business as the cruise industry, earning the money before the costs expenditures is very helpful since it reduces the risk of liquidity problems.

Throughout the years, some authors studied the use of revenue management techniques, commonly seen in the airline and hotel industry, to the cruise industry. Basically, revenue management is the class of practices used to maximize the revenue of a product which have limited inventory capacity (such as seats in an airplane, rooms in a hotel or cabins in a cruise ship) by segmenting customers and selling the same product to different segments with a different price.

Sun et al. (2011) conducted a concise review about marketing research and revenue optimization for the cruise industry, giving a better view about how it is applied in the cruise industry as well as in other industries. Ladany et al. (1991) introduced this technique to the cruise industry, by calculating the total revenue that the cruise company would earn from different price strategy scenarios and assuming a linear demand curve: optimal single-market single-price strategy, maximal market-separation strategy, market segmentation of the unused capacity, unconstrained market segmentation of all cabins and unconstrained market segmentation of all cabins assuming customer infiltration.

Niavis et al. (2018) studied the price structure of a cruise ticket, proposing the decomposition of this price as a combination of tourism and transportation characteristics, using a hedonistic pricing modelling method, which consist of decomposing a product into attributes and describing the product price as an additive function of all attributes. The tourism characteristics of the product used are onboard amenities and leisure activities, service quality, duration of trip, season, and itinerary attractiveness. The transport characteristics considered are sailing speed and itinerary closeness.

2.4 Cruise Ship Itinerary Design

The objective of the cruise ship itinerary design problem is to encounter the best route given a set of possible ports of call. Usually, the homeport location and the duration of the itinerary are defined, but a difficult problem arises when attempting to determine the demand for the itinerary, since it depends on the itinerary itself and no universal method is known to accurately carry out such estimates. This problem is found in the literature under various names: cruise itinerary design, cruise ship itinerary design, cruise ship itinerary and schedule design. In this paper, the acronym CSID (cruise ship itinerary design) will be used to designate this problem. Wang et al. (2016) argues that itinerary design, fleet management, ship deployment and service planning are unknown areas of the industry which have an important effect on the profitability of cruise companies. Itinerary design is part of a major class of problems, known as vehicle routing problems (VRP), an important topic of operations research field. The basic VRP consists of finding the best route given that it must start and end at the same place and the vehicles must pass only one time through each destination.

This problem is also a generalization of the travelling salesman problem (TSP), which is one of the most famous combinatorial optimization problems. In recent years, VRP problems with more complex constrains (such as time windows, capacity constraints and service time) lead to the creation of a newer class of problems, called rich vehicle routing problems (RVRP), as suggested by Lahyani et al. (2015), where the cruise itinerary schedule design problem can be included. Additionally, is also possible to consider the CSID problem in a category called traveler salesman problems with profits, which incorporates the idea of profits into the typical traveling salesman problem, as discussed by Feillet et al. (2005).

Ladany et al. (1989) made one of the first attempts to solve a problem in this topic by studying how to maximize the revenue given by a leased luxury cruise ship sailing at Caribbean seas, using a dynamic programming model to optimize the maximum revenue for the season. Continuing the study in this area, Ladany et al. (2001) presented an intuitive near-optimal heuristic method for solving the cruise itinerary problem with an objective function of maximizing the local attractiveness of the itinerary. Verdet et al. (2011) showed how the complexity of these problems increases when multiple ships must be considered at the same time, combing the problem of itinerary design with the problem of fleet assignment. Yang et al. (2016) studied a cruise itinerary optimization problem in the coastline of China. The model developed uses dual objectives, trying to maximize the quantity of passengers with the minimum operating costs, solving it with a genetic algorithm based on matrix coding.

Wang et al. (2017) published a mathematical model to solve the itinerary schedule design problem given the departure time and arrival time at homeport. Instead of estimating the passenger’s demand for each destination, a utility distribution is used to measure the advantages of spending more time at a city instead of spending that same time at sea. A more complex problem was presented by Wang, Kai et al. (2017), who tried to maximize the total profit of a cruise itinerary during a planning horizon, considering the berth availability of each port of call and a decreasing marginal profit. Another itinerary optimization
model which has been elaborated in collaboration with a cruising company is presented by Asta et al. (2018). In this study, a purely cruise itinerary design model is developed, requiring as input a set of possible ports of call, voyage duration and homeport location. Mancini et al. (2018) used a variant of the vehicle routing problem to propose a model of cruise itinerary design combined with fleet assignment problem. A different approach was made by Chen et al. (2018) which used the Weibull duration model to measure which factors influence the time a cruise ship stays at a given port. Carillo et al. (2019) evaluated time and cost of solving the cruise ship itinerary design problem using the cloud with an optimization via simulation process using a tabu-search approach. To combine itinerary design with revenue management strategies, Guo et al. (2019) used a two-stage optimization model where during the first stage, the best itinerary is chosen and, at the second stage of the optimum cabin price is calculated.

3 OPERATIONS RESEARCH IN THE CRUISE SHIP ITINERARY DESIGN

In this section, a basic mathematical definition of the Vehicle Routing Problem is presented, and the CSID problem is detailed.

3.1 The Traveling Salesman Problem (TSP) and Vehicle Routing Problem (VRP)

The traveling salesman problem consists of finding the optimal tour (cycle) passing through all the destinations exactly once, given only the costs of traveling between them. Although this problem does not provide an accurate solution for many of the routing problems faced by the industries today, it is still widely studied given its simplicity and difficulties to solve, and that the TSP is equivalent to others np-hard problems, which means finding a solution for the TSP is equivalent to finding a solution of many other problems. Moreover, the TSP is divided into two broad classes of problems: the symmetric TSP (STSP) and the asymmetric TSP (ATSP). Those classifications are directly linked to the definition of a direct graph and an indirect graph. A graph $G$ is defined by two different sets, written as $G = (V, A)$, where $V$ is the set of nodes and $A$ is the set of ordered or unordered pairs of vertices of $V$. When $A$ is an ordered set, each element of this set is called an arc and $G$ is said to be a direct graph. Conversely, when $A$ is an unordered set, each element of this set is called an edge and $G$ is said to be an indirect graph.

Following this definition, it is easy to observe that the STSP is related to an indirect graph whereas the ATSP is related to a direct graph. Despite of these differences, a STSP can be transformed into an ATSP problem simple by adding to the graph a set of arcs in opposite direction of all existing edges. Therefore, all algorithms described by the ATSP can be used for solving the STSP, although on many occasions the performance of the algorithm is compromised. Gutin et al. (2007) shows different variations of the TSP and techniques to solve it, including exact and approximated solutions.

The Vehicle Routing Problem is a generalization of the TSP, designed mainly to be used for assigning an optimal route for a fleet of vehicles. Usually, each node has a specific demand to be attended and there will be as many tours in the final solution as there are vehicles available in the problem. Typically, in a VRP, each vehicle has a limited capacity, and a fixed cost is associated with its use. Golden et al. (2008) discusses in more details about the vehicle routing problem and its variations. A formulation for the VRP is shown in the paragraph below.

Let $D$ be a complete direct graph, given by $D = (V, A)$, where the first node represents the depot, the set $M = \{1, 2, ..., k\}$ is the set of types of vehicles available in the fleet, $c = \{c_{ij}, i,j \in V \mid c_{ij} \geq 0\}$ represents the cost of traveling from any two nodes $i$ and $j$ of the graph, $F = \{F_k, k \in M\}$ be the fixed cost of using each vehicle, $Q = \{Q_k, k \in M\}$ is equal to each vehicle capacity, $q = \{q_i, i \in V \setminus \{1\}\}$ represent the demand at each node and $m = \{m_k, k \in M\}$ is the total number of each type of vehicles available in the fleet. Then, introducing two decision variables, $x = \{x_{ij}^k, (i,j) \in A, k \in M\}$ which tells whether a type $k$ vehicle is assigned to travel from node $i$ to node $j$, and $y = \{y_{ij}, i,j \in V\}$, which tells the quantity of cargo carried from node $i$ to node $j$, one may express the formulation as:

$$\min \sum_{k \in M} F_k \sum_{j \in V \setminus \{1\}} x_{0,j}^k + \sum_{k \in M} \sum_{i,j} c_{ij}^k x_{i,j}^k$$

subject to:

$$\sum_{k \in M} x_{i,j}^k \leq 1 \forall j \in V \setminus \{1\}$$

$$\sum_{k \in M} x_{i,p}^k - \sum_{k \in M} x_{p,j}^k = 0 \forall p \in V \setminus \{1\}, \forall k \in M$$

$$\sum_{k \in M} x_{i,j}^k \leq m_k \forall k \in M$$

$$\sum_{k \in M} y_{i,j} - \sum_{k \in M} y_{j,i} = q_j \forall j \in V \setminus \{1\}$$

$$q_j x_{ij}^k \leq y_{i,j} \leq (q_k - q_j) x_{ij}^k \forall (i,j) \in A, \forall k \in M$$

$$y_{i,j} \geq 0 \forall (i,j) \in A$$

$$x_{ij}^k \in \{0, 1\} \forall (i,j) \in A, \forall k \in M$$

3.2 Cruise Ship Itinerary Design Problem (CSID)

The problem to be studied consists of identifying the most profitable itinerary route in a certain geographical region given a list of possible ports of call for that region. The cruise ship is known and therefore its main dimensions and passenger capacity are given parameters. Additionally, the month of the year and the duration of the itinerary, in days, are also previously defined. For each voyage leg, the ship is assumed to sail at a constant speed, selected from a set of possible speeds, and restricted by a maximum number of hours at sea. Higher sailing speed means higher achievable sailing distances in each leg but also imply higher fuel consumption. Every itinerary must have one homeport and each port of call must be visited only once. When convenient, the cruise ship can stay a full day at sea, in order to avoid having to visit cities not so attractive or in order to visit an extremely interesting destination very distant from the previous destination visited in the itinerary. Summarizing, the problem analyzed involves identifying the sequence of ports of call to be visited and the sailing speed in each itinerary leg, so that the highest net profit for the cruise company is obtained.

4 MATHEMATICAL FORMULATION

In order to solve this problem, a mathematical model needs to be formulated, based on the Vehicle Routing Problem formulation described in the previous section. This problem will then be solved with CPLEX 12.10. For an easier understanding, the model is divided into the following topics:
assumptions, main equations, revenue expression and the subtour constraint adopted.

4.1 Assumptions and Simplifications

The assumptions used to develop this model are:

1. Voyage time between two ports depends only on the distance between those ports and the ship speed, assumed constant for the entire trip.
2. The cruise itinerary must end in the starting port.
3. Each port of call must be visited only once.
4. The ship can visit at maximum one port per day.
5. The itinerary must have precisely the duration time desired.
6. Main engine power of the ship is proportional to the cubic power of the speed.
7. Load factor (L.F.) of the auxiliary power is constant during the entire voyage (at sea and at port).
8. The specific fuel oil consumption (S.F.O.C.) for the main engine and auxiliary engine are assumed to be constant, regardless of the engines load factor.
9. Main engine consumes intermediate fuel oil (IFO 180) and auxiliary engine consumes marine gas oil (MGO). The prices of these oils are input parameters and therefore constants.
10. The fixed costs are constant, regardless of the month studied or the ports included in the itinerary.
11. The cruise ship is assumed to operate with two passengers per cabin always.
12. The revenue collected depends exclusively on the month and the ports included in the itinerary.
13. Ships can only arrive at ports between 7:00 and 14:00 and can only depart during 16:00 and 23:00.

4.2 Parameters

The parameters are divided into four categories: route, costs, revenue, and dimension, as show below. Sets are defined starting with capital letters and the other parameters starts with lowercase.

4.2.1 Route

Let \( n \) be the number of all possible ports for this problem and \( P = \{1, \ldots, n\}, P \subset \mathbb{N} \) be the set of all possible ports and \( \overline{hP}_i = \{0,1\}, \forall i \in P \) the parameter representing whether a port can be a homeport or not (if a port \( i \) can be assigned as a homeport, \( \overline{hP}_i = 1 \) and if not, \( \overline{hP}_i = 0 \)). Similarly, let \( g \) be the number of speeds being considered and \( S = \{1, \ldots, g\}, S \subset \mathbb{N} \) be the set of all possible ship speeds. The speeds values considered, in knots, are given by \( v_p, i \in S \).

Let \( E = \{(i,j,k) | i, j \in P, k \in S : i \neq j\} \) to be the set of all possible arcs formed by two different ports and the different speeds and let \( L = \{(i,j) | i, j \in P : i \neq j\} \) to be the set of all possible arcs between two different ports.

The ports distance is given by \( d_{ij}, (i,j) \in L \), given in nautical miles and the time between ports is given by \( t_{ij,k}, (i,j,k) \in E \).

The duration of the itinerary, in nights, is given by the parameter \( \Delta \). In relation to the month when the itinerary will occur, let \( M = \{january, \ldots, december\} \) be the set of months of the year and \( m \) the month when the itinerary occurs.

Let \( s_{\text{min}} \) and \( s_{\text{max}} \) being respectively the minimum and maximum time in port at each port of call, in hours, \( t_{\text{leg}}^{\text{max}} \) being the maximum travelling time during each voyage leg, in hours.

4.2.2 Costs

The fixed cost parameters are enumerated in the following list and their value is expressed in USD/day: \( c_e \) (capital costs), \( c_w \) (crew wages), \( c_s \) (storage and provisions cost), \( c_{rm} \) (regular maintenance cost), \( c_i \) (insurance cost), \( c_a \) (administration cost), and \( c_{pm} \) (periodic maintenance cost).

The specific fuel oil consumption (S.F.O.C.), in Kg/Kwh, consumption for each possible speed of the main engine and the S.F.O.C., in Kg/kwh, for the auxiliary engines are given respectively by \( sfoc_{M,i} \in S \) and \( sfoc_{aux} \). Additionally, its prices, in USD/ton, are given by the parameters \( hfo \) and \( mgo \). Normal continuous rating (N.C.R) of the ship, in kW, and the cruise speed, in knots, are given by \( ncr \) and \( v_{cruise} \) respectively. The power consumption of each speed, in kW, for the main engine and the auxiliary engine are given by \( p_{M,i} \in S \) and \( p_{aux} \). The value of main engine power for speeds different than the cruise speed is given by:

\[
p_{M,i} = \left(\frac{v_i}{v_{cruise}}\right)^3 \cdot ncr
\]

The value of the main engine fuel cost, in USD/hour, is given by:

\[
c_{\text{main}i} = p_{M,i} \cdot sfoc_{M,i} \cdot mgo \text{, } i \in S
\]

The value of the auxiliary engines fuel cost, in USD/hour, is given by:

\[
c_{\text{aux}} = p_{aux} \cdot L \cdot F \cdot sfoc_{aux} \cdot \frac{mgo}{1000}
\]

Ports tariffs will depend on the ports included at the analysis and is denoted by the parameter \( c_{\text{tariff},i} \in \mathbb{P} \), expressed in USD.

4.2.3 Revenue

The total revenue of the itinerary, in USD, is calculated as described in the Cruise Planner Manual (Santos, 2020), and is a function of the attractiveness of each port, shown by the formula below:

\[
V_{i,m} = p_t + A_i \left(\frac{12 - 2Ta_i}{12}\right) + 2(Tm_{i,m} - 15) + 0.1(S_{i,m} - 200) - 5(Hs_{i,m} - 1.5), \ i \in \mathbb{P} \text{ and } m \in M
\]

where,

1. \( V_{i,m} \) is the total port attractiveness of the port \( i \) for the month \( m \), in USD/passenger.
2. \( p_t \) is the attractiveness of the port itself.
3. \( A_i \) is the attractiveness of a city or attraction located near the port of call.
4. \( Ta_i \) is the time, in hours, from the port \( i \) to the attraction located near the port of call.
5. \( Tm_{i,m} \) is the average daily temperature, in degrees Celsius, in the port \( i \) for the month \( m \).
6. \( S_{i,m} \) is the average monthly sunshine hours in the port \( i \) for the month \( m \).
7. \( H_{\text{s},t,m} \) is the average significant wave height, in meters, in the port \( t \) for the month \( m \).

This formula combines weather and geographical factors of each destination with the attractiveness of the location itself to calculate the total attractiveness of the port. The first two terms are related to the attractiveness of the port and the attractions nearby, if any, taking into consideration the distances to the port \( t \) (the further the nearby attractions are to the port, the less attractive it became). For the weather characteristics, namely average daily temperature, average monthly sunshine hours and average significant wave height, it can influence linearly the final value of the port attractiveness. Higher average daily temperature and average monthly sunshine hours influence positively the port attractiveness whereas bigger average significant wave height influence negatively the total port attractiveness. These weather factors are the only parameters that varies depending on the month analysed.

Weather values were taken directly from the internet, with exception of the average wave height value which were calculated using the program ERA5. To estimate the attractiveness of a port or a nearby attraction, the following formula is used, taking as a parameter the number of tourists that visits the city annually:

\[
P_t = 25 + 150 * \frac{\text{maximum number of tourists visiting the city} \text{ in the selection annually}}{\text{number of tourists visiting the city} \text{ in the selection annually}}
\]  
\[= 25 + 150 \times \frac{\text{number of tourists visiting the city} \text{ in the selection annually}}{\text{number of tourists visiting the city} \text{ in the selection annually}}
\]  
\[= 25 + 150 \times \frac{\text{number of tourists visiting the city} \text{ in the selection annually}}{\text{number of tourists visiting the city} \text{ in the selection annually}}
\]  
\[= 25 + 150 \times \frac{\text{number of tourists visiting the city} \text{ in the selection annually}}{\text{number of tourists visiting the city} \text{ in the selection annually}}
\]

4.2.4 Dimension

The final parameters to be considered are the dimensional parameters of the ship and each port. The ship parameters considered are \( n_{\text{pax}} \) (number of passengers), \( L_{\text{ship}} \) (length of the cruise ship in meters), \( B_{\text{ship}} \) (breadth of the cruise ship in meters), and \( D_{\text{ship}} \) (draught of the cruise ship in meters).

The port parameters considered are the maximum allowed length, breadth and draught of the ships docking at the port, expressed respectively by \( L_{\text{i}}, B_{\text{i}}, D_{\text{i}} \in P \), and \( B_{\text{i}}, D_{\text{i}} \in P \).

4.3 Variables

For this problem there are Boolean variables, integer variables and real variables. The Boolean variables are:

1. \( x_{i,j,k}, (i,j,k) \in E \): 1 if the ship travels from port \( i \) to port \( j \) with speed \( k \).
2. \( y_{i}, i \in P \): 1 if the port \( i \) is part of the itinerary.
3. \( h_{\text{p}}, i \in P \): 1 if the port \( i \) is the homeport.
4. \( \hat{x}_{i,j}, (i,j) \in L \): 1 if the ship stays one day at the sea between the arc \( l \).

The integer variables are:

1. \( a_{i}, i \in P \): Hour of the day that the ship arrives at the port \( i \).
2. \( b_{i}, i \in P \): Hour of the day that the ship departs from the port \( i \).

Finally, the real variable is:

1. \( u_{i}, i \in P \): Subtour elimination variable.

4.4 Expressions

in order to facilitate the comprehension of the objective function and the constraints, some expressions will be defined and used later on. These expressions are divided in three categories, time related expressions, cost related expressions and revenue related expressions, as shown below.

4.4.1 Time Related Expressions

Time in port is the total time that the ships stays at each port, given by:

\[ s_{i} = b_{i} - a_{i}, \forall i \in P \]  
\[ (14) \]

The time at sea during the cruise voyage for each two ports and the total sea time for the entire voyage are given by:

\[ t_{\text{leg}_{i,j}} = \sum_{k \in S} (t_{i,j,k} * x_{i,j,k}) \forall (i,j) \in L \]  
\[ (15) \]

\[ t_{\text{sea}} = \sum_{(i,j) \in L} t_{\text{leg}_{i,j}} \]  
\[ (16) \]

The total onboard time is a measure of the total time passengers stay onboard the ship, which included the sea time and the waiting time, as seen below.

\[ t_{\text{onboard}} = \sum_{(i,j) \in L} \sum_{k \in S} \left( (a_{j} + (24 - b_{i}) + 24 * \hat{x}_{i,j}) * x_{i,j,k} \right) \]  
\[ (17) \]

Moreover, knowing the total sea time and the total onboard time, is possible to calculate the total waiting time for the itinerary:

\[ t_{\text{waiting}} = t_{\text{onboard}} - t_{\text{sea}} \]  
\[ (18) \]

4.4.2 Cost Related Expressions

Cost related expressions used in this model are based on D’Almeida, J. (2009). The fixed cost is given by the sum of all fixed cost parameters:

\[ c_{\text{fixed}} = \Delta * \left( c_{e} + c_{s} + c_{r} + c_{p} + c_{t} + c_{c} + c_{p} \right) \]  
\[ (19) \]

where the cost components were defined 4.2.3. These are relative to the ship’s characteristics and are an input.

The main engine fuel consumption total cost is given by:

\[ c_{\text{main}} = \sum_{(i,j,k) \in E} \left( x_{i,j,k} * t_{i,j,k} * c_{\text{main}} \right) \]  
\[ (20) \]

Auxiliary engines cost is divided in two situation: auxiliary engine cost when the ship is docked (equation 21) and auxiliary engine cost when the ship is sailing (equation 22). The difference between these two situations are the number of hours that the ship spent in each situation and the reduced electrical power consumption when the ship is docked. This reduction in auxiliary power consumption is defined by the load port factor (L.P.F) parameter.

\[ c_{\text{port}} = c_{\text{aux}} * L \cdot F \cdot P * \sum_{i \in P} (s_{i} * y_{i}) \]  
\[ (21) \]

\[ c_{\text{aux}} = c_{\text{aux}} * \sum_{(i,j,k) \in E} \left( x_{i,j,k} * t_{i,j,k} \right) \]  
\[ (22) \]

The total port tariffs is calculated by:

\[ c_{\text{tariffs}} = \sum_{i \in P} \left( c_{\text{tariff}} * y_{i} \right) \]  
\[ (23) \]
The waiting cost is added to apply a small penalty for having the ship waiting at the port, as shown below. The idea is that while this value will not represent a significant difference, it will incentive the cruise ships to not stay waiting to enter at the port unless necessary.

\[
c_{\text{waiting}} = t_{\text{waiting}} \times n_{\text{pax}} \times 10 \tag{24}
\]

The total itinerary cost can be obtained by:

\[
C_{\text{total}} = c_{\text{main}} + c_{\text{aux}} + c_{\text{port}} + c_{\text{fixed}} + c_{\text{waiting}} + c_{\text{tariffs}} \tag{25}
\]

### 4.4.3 Revenue Related Expressions

The total gross revenue collected in the itinerary is given by:

\[
R = \sum_{i \in P} (2 \times V_{i,m} \times n_{\text{pax}} \times y_i) + \sum_{(i,j) \in L} (10 \times n_{\text{pax}} \times \hat{x}_{i,j}) \tag{26}
\]

### 4.5 Objective Function

The objective function of this model is to maximize the itinerary net profit, expressed by:

\[
\text{max} \ (R - C_{\text{total}}) \tag{27}
\]

### 4.6 Constraints

Finally, the last part of the model to be showed are the model constraints. Variables constraints represents all constraints related to the nature of the variables and its allowed values. Flow constraints are used to guarantee that the ship will visit each port only once, there will be at least one port at the itinerary included at the list of possible homeports assigned and that the maximum traveling is respected in each leg. The time constraints guarantee that the ship arrives and departs at each port during the allowed time window period and that the itinerary has the exact duration desired. Dimensions constraints are used to check whether the ship can dock at all ports in the itinerary. Finally, the sub route constraint is used to eliminate possible subtour solutions.

#### 4.6.1 Variables Constraints

Other than the variables set constraints detailed above, there are two other constraints included in this model, equations (28) and (29), related to the allowed arrival and departure time at each port, respectively.

\[
7 \leq a_i \leq 14, \forall i \in P \tag{28}
\]

\[
16 \leq b_i \leq 23, \forall i \in P \tag{29}
\]

#### 4.6.2 Flow Constraints

Equations (30) and (31) guarantees that if the ship makes round voyages, although it not necessarily guarantees that there is only one route in the optimal solution. Equation (32), (33) and (34) forces the desired homeport to be part of the itinerary. Equation (35) constrains the ship to have only one possible speed during each leg and, equations (36) and (37) forces the variable \( \hat{x}_{i,j} \) to be true only on possible scenarios (when the ship is traveling through this route). Although not required in the model, the constraint (38) showed to decrease significant the solving time. Finally, equation (39) forces \( a \) and \( b \) values to be physically possible.

\[
\sum_{k \in S} \sum_{j \in P} x_{i,j,k} = y_i, \forall i \in P \tag{30}
\]

\[
h p_i \leq y_i, \forall i \in P \tag{32}
\]

\[
\sum_{i \in P} h p_i = 1 \tag{33}
\]

\[
h p_i \leq \bar{h} p_i, \forall i \in P \tag{34}
\]

\[
\sum_{i \in P} \bar{x}_{i,j,k} \leq 1, \forall (i,j) \in L \tag{35}
\]

\[
\sum_{i \in P} \bar{x}_{i,j} \leq 1, \forall i \in P \tag{36}
\]

\[
\sum_{i \in P} \bar{x}_{i,j} \leq 1, \forall j \in P \tag{37}
\]

\[
if \ (\bar{x}_{i,j} = 1) \ then \ (\sum_{k \in S} x_{i,j,k} = 1), \forall (i,j) \in L \tag{38}
\]

\[
a_j + (24 - b_j) + 24 \times \bar{x}_{i,j} \geq t_{\text{leg},i,j}, \forall (i,j) \in L \tag{39}
\]

#### 4.6.3 Time Constraints

Equations (40) and (41) constrains applies the maximum time at sea constrains. Equations (42) and (43) defines the minimum and maximum time of each port visit, excluding the homeport, and the equation (44) forces the itinerary to have the desired duration.

\[
t_{\text{leg},i,j} \leq t_{\text{leg}} \times 24 \times \bar{x}_{i,j}, \forall (i,j) \in L \tag{40}
\]

\[
t_{\text{leg}} = 15 \tag{41}
\]

\[
s_i \geq s_{\text{min}} \times (1 - h p_i), \forall i \in P \tag{42}
\]

\[
s_i \leq s_{\text{max}} \times (24 - s_{\text{max}}) \times h p_i, \forall i \in P \tag{43}
\]

\[
\sum_{i \in P} y_i + \sum_{\ell \in L} \bar{x}_{i,j} = \Delta \tag{44}
\]

#### 4.6.4 Dimensions Constraints

Equations (45), (46) and (47) forces the ship dimensions to be lower than the ports restrictions.

\[
L_{\text{ship}} \times y_i \leq L_i, \forall i \in P \tag{45}
\]

\[
B_{\text{ship}} \times y_i \leq B_i, \forall i \in P \tag{46}
\]

\[
D_{\text{ship}} \times y_i \leq D_i, \forall i \in P \tag{47}
\]

#### 4.6.5 Sub Route Constraint

The last constrain, given by equation (48) is used to eliminate sub tour solutions. This sub tour constraint is an adaptation of the MTZ constraint, based on the idea given by Gouveia et al. (1999) and Yuan et al. (2020), for the case where the depot (homeport in this case) exists but is not known at the beginning.

\[
u_i - u_j + (\Delta - 1) \times \sum_{k \in S} x_{i,j,k} \leq \Delta - 2 + \Delta \times (h p_i + h p_j), \forall i, j \in P : j \neq i \tag{48}
\]
5 CASE STUDY

To analyze this model and investigate how it behaves in relation to existing itineraries, numerical studies are made for the Atlantic coast of the Iberian Peninsula. Santos (2020) presents a detailed study about the cruising shipping activity in the Atlantic Coast of the Iberian Peninsula, analyzing the cruise ships of the region and how it compares with the rest of the Mediterranean Sea and the world.

A specific ship is selected, and results for different scenarios are compared with existing itineraries of the region. The analysis is made for weekly itineraries (8 days-7 nights), during Summer (August), and Winter (January). For both seasons, two optimizations are done, one including only typical cruise ports of the region (as-is situation) and another one including an extended list of cruise ports (improved situation). Moreover, the computational aspects of all analyses performed are presented at the end of this section. The list of ports considered in this case study are shown in the figure 1 and figure 2. A list with the attraction value of each port can be seen at Table 2. These values were calculated according to equation (13).

---

**Figure 1:** List of ports considered for the case study of the Mediterranean Sea and the world.

**Figure 2:** List of ports considered at the Morocco Coast.

The ship chosen for this analysis a cruise with 1025 cabins. For this study, is assumed that there will always be 2 passengers per cabin, regardless of the itinerary.

Table 1 details the technical characteristics of the ship and, the set of possible speeds considered is \{10,11,12,13,14,15,16,17,18,19,5,20,21\}.

<table>
<thead>
<tr>
<th>Port</th>
<th>Val. of Port</th>
<th>Val. of Attract. On Nearby</th>
<th>Distance to Attract. (km)</th>
<th>Time to Attract. (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Coruña</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vigo</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leixões</td>
<td>30</td>
<td>65</td>
<td>14</td>
<td>0.5</td>
</tr>
<tr>
<td>Lisbon</td>
<td>98</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Portimão</td>
<td>31</td>
<td>29</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cádiz</td>
<td>31</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Málaga</td>
<td>54</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tanger Ville</td>
<td>37</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Casablanca</td>
<td>46</td>
<td>32</td>
<td>90</td>
<td>1.25</td>
</tr>
<tr>
<td>Agadir</td>
<td>31</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Funchal</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anzère</td>
<td>53</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Puerto del Rosario</td>
<td>46</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Las Palmas</td>
<td>45</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S. Cruz de Tenerife</td>
<td>52</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Palma</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S. Sebastián de Gomera</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Viana do Castelo</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aveiro</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Figueira da Foz</td>
<td>28</td>
<td>32</td>
<td>57</td>
<td>0.75</td>
</tr>
<tr>
<td>Setúbal</td>
<td>28</td>
<td>31</td>
<td>100</td>
<td>1.25</td>
</tr>
<tr>
<td>Faro</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Huelva</td>
<td>26</td>
<td>59</td>
<td>95</td>
<td>1.25</td>
</tr>
<tr>
<td>Motril</td>
<td>26</td>
<td>64</td>
<td>71</td>
<td>1</td>
</tr>
<tr>
<td>Ceuta</td>
<td>26</td>
<td>29</td>
<td>40</td>
<td>1.5</td>
</tr>
<tr>
<td>Kenitra</td>
<td>32</td>
<td>36</td>
<td>154</td>
<td>2</td>
</tr>
<tr>
<td>Safi</td>
<td>26</td>
<td>100</td>
<td>158</td>
<td>2.25</td>
</tr>
<tr>
<td>Vilagarcia de Arousa</td>
<td>26</td>
<td>50</td>
<td>54</td>
<td>0.75</td>
</tr>
</tbody>
</table>

5.1 As-is Situation

5.1.1 Winter Solution

The ports obtained by the optimization for the Winter analysis of the as-is-situation are Málaga, Tanger, Lisbon, Leixões, Casablanca, and Gibraltar, resulting in a total attraction value of about 340 USD/pax. The resulting route is composed by the four most valuable ports (Lisbon, Leixões, Málaga, and Casablanca) and by the ports of Gibraltar and Tanger, which although not
having big attraction value, are located between Lisbon, Málaga, and Casablanca making them a good solution to travel through these locations without having to increase the ship speed or requiring to stay one extra day at sea. This route is shown in the figure 3.

Figure 3: Optimum itinerary for a weekly cruise in Winter, as-is-situation of the Atlantic Coast of Iberian Peninsula

5.1.2 Summer Solution

The ports chosen for the Summer analysis of the as-is-situation are Málaga, Gibraltar, Casablanca, Leixões, Lisbon, and Tanger. The itinerary of this case contains the same ports of the Winter route, but in a different order. Because of that, the total cost of both itineraries is equal however, the gross revenue is not, given that the total attraction value during Summer is higher. In fact, the total gross revenue is 75% bigger and the profit is 350% larger in comparison with Winter route. The Summer route is shown in the figure 4.

Figure 4: Optimum itinerary for a weekly cruise in Summer, as-is-situation of the Atlantic Coast of Iberian Peninsula

5.1.3 Model Validation

Solutions obtained for the as-is-situation with the optimization model are compared with the list of busiest cruise ports obtained from the passenger traffic statistics of 2018 for the ports considered are shown at Table 3. Comparing this data with the list of ports obtained from the as-is-situation, one may see that out from all ports included at the Winter or Summer itinerary (Lisbon, Málaga, Cádiz, Gibraltar, Leixões, Casablanca, and Tanger Ville), two of them are received more than 500,000 passengers in 2018, Lisbon and Málaga. Furthermore, three of the ports received between 100,000 and 500,000 passengers, Cádiz, Leixões and Gibraltar, and two of the ports received less than 100,000 passengers, Casablanca and Tanger. Another interesting point is that both itineraries selected the port of Málaga to be the homeport, which is one of the most important homeports of the region, after Las Palmas and Santa Cruz de Tenerife.

Table 3: Passenger traffic statistics of 2018 for the ports at the Atlantic Coast of the Iberian Peninsula.

<table>
<thead>
<tr>
<th>PORTS</th>
<th>TOTAL PASSENGERS [THOUSANDS]</th>
<th>TRANSIT PASSENGERS</th>
<th>NUMBER OF CALLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Las Palmas Port</td>
<td>676</td>
<td>250</td>
<td>255</td>
</tr>
<tr>
<td>Port of Santa Cruz de Tenerife</td>
<td>618</td>
<td>480</td>
<td>298</td>
</tr>
<tr>
<td>Port of Lisbon</td>
<td>578</td>
<td>516</td>
<td>339</td>
</tr>
<tr>
<td>Port of Funchal</td>
<td>541</td>
<td>537</td>
<td>293</td>
</tr>
<tr>
<td>Port of Málaga</td>
<td>507</td>
<td>399</td>
<td>298</td>
</tr>
<tr>
<td>Port of Cádiz</td>
<td>425</td>
<td>423</td>
<td>334</td>
</tr>
<tr>
<td>Port of Arrecife</td>
<td>423</td>
<td>421</td>
<td>217</td>
</tr>
<tr>
<td>Port of Gibraltar</td>
<td>407</td>
<td>407</td>
<td>243</td>
</tr>
<tr>
<td>Port of Santa Cruz de la Palma</td>
<td>246</td>
<td>246</td>
<td>153</td>
</tr>
<tr>
<td>Port of Puerto del Rosario</td>
<td>234</td>
<td>233</td>
<td>114</td>
</tr>
<tr>
<td>Port of A Coruña</td>
<td>179</td>
<td>178</td>
<td>94</td>
</tr>
<tr>
<td>Port of Vigo</td>
<td>158</td>
<td>157</td>
<td>70</td>
</tr>
<tr>
<td>Port of Leixões</td>
<td>117</td>
<td>115</td>
<td>101</td>
</tr>
<tr>
<td>Port of Agadir</td>
<td>106</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Port of San Sebastián de la Gomera</td>
<td>88</td>
<td>88</td>
<td>64</td>
</tr>
<tr>
<td>Port of Casablanca</td>
<td>70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Port of Portimão</td>
<td>37</td>
<td>36</td>
<td>66</td>
</tr>
<tr>
<td>Port of Tanger Ville</td>
<td>31</td>
<td>31</td>
<td>46</td>
</tr>
<tr>
<td>Port of Ceuta</td>
<td>16</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Port of Huelva</td>
<td>12</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Port of Motril</td>
<td>5</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Port of Vilagarcia de Arousa</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

5.2 Improved Situation

5.2.1 Winter Solution

The itinerary chosen by the model contains the ports of Lisbon, Gibraltar, Motril, Ceuta, Safim, Casablanca, and Huelva, summing an itinerary attraction value of 460.1 USD/passenger. The possibility of selecting ports located close to the entrance of Mediterranean Sea, such as Safim, Motril, and Huelva, made the optimal itinerary shift to the South, not including Leixões into the route. Despite of that, no ports from the Canary or Madeira islands appears on this solution, as shown in figure 5.

Figure 5: Optimum itinerary for a weekly cruise in Winter, improved situation of the Atlantic Coast of Iberian Peninsula.
The itinerary chosen by the model contains the ports of Lisbon, Leixões, Setúbal, Casablanca, Safim, Gibraltar and, Huelva, summing an itinerary attraction value of 731 USD/passenger. This itinerary has three ports included at the improved port’s list: Setúbal, Safim, and Huelva. The port of Leixões returned to the optimal solution, highlighting the fact that although Leixões have a great attraction value, the cold weather during Winter provides a big negative impact to the city, reducing its attraction value in 40 points.

Moreover, the port of Setúbal was not chosen because of its attraction value but rather because it is the only option for traveling from Leixões to the south of the Iberian Peninsula or Morocco and not having to stay one day at sea during the travel to other attractive ports. The route obtained is presented at figure 6.

![Figure 6: Optimum itinerary for a weekly cruise in Summer, improved situation of the Atlantic Coast of Iberian Peninsula.](image)

5.3 Itineraries Comparison

Finally, to evaluate and quantify if there are significant advantages on the Winter and Summer improved situation itineraries, a comparison between as-is-situation solution and improved solutions is made, using as an indicator the total profit per passenger per voyage.

The Winter as-is-situation itinerary resulted in a total attraction value of 340 USD/passenger, passing through the ports of Málaga, Tanger, Lisbon, Leixões, Casablanca, and Gibraltar. For the improved situation, the solution returned an itinerary with attraction value of 460 USD/passenger, 35% higher than the as-is-situation, as shown at Table 6. Comparing both routes, only three ports are equal on both cases: Lisbon, Casablanca, and Gibraltar. The other ports of the as-is-situation were substituted for more attractive ports, closer to each other and in Morocco or South of Spain, regions situated closer to tropical zones. The increase of profits from both cases is practically equal to the increase in gross revenue.

Table 4: Comparison between costs and revenue for the as-is-situation and improved situation study of the Atlantic Coast of Iberian Peninsula during Winter.

<table>
<thead>
<tr>
<th></th>
<th>AS-IS-SITUATION</th>
<th>IMPROVED SITUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fuel Costs</td>
<td>$137,199</td>
<td>$168,337</td>
</tr>
<tr>
<td>Port Tariffs</td>
<td>$138,123</td>
<td>$123,739</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$1,089,057</td>
<td>$1,106,732</td>
</tr>
<tr>
<td>Gross Revenue</td>
<td>$2,444,652</td>
<td>$2,996,389</td>
</tr>
<tr>
<td>Total Profits</td>
<td>$1,355,596</td>
<td>$1,889,658</td>
</tr>
<tr>
<td>Profit/passenger</td>
<td>???</td>
<td>???</td>
</tr>
</tbody>
</table>

For both the Winter and Summer analysis, the inclusion of more possible ports of call yielded in a more profitable solution.

5.4 Computational Aspects

The CPU used to run these optimizations is a i5-8250U CPU. As expected, the time required to obtain the optimal solution grew exponentially with the number of possible ports of call. Table 6 presents the relation between quantity of possible ports of call, quantity of variables in the optimization and time required. As it can be seen, the program runs in less than 6 minutes for all cases analyzed. Moreover, another parameter that influence in the optimization time is the possible speeds that the ship can have, despite of not affecting a specific optimization case in this paper since all the studies used the same number of possible speeds.

Table 6: Computational aspects of the optimization runs.

<table>
<thead>
<tr>
<th>CASE STUDY</th>
<th>NUMBER OF PORTS</th>
<th>NUMBER OF VARIABLES</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iberian Peninsula: as-is-situation</td>
<td>18</td>
<td>4,680</td>
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<td>Iberian Peninsula: improved situation</td>
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6 CONCLUSIONS

Cruise itineraries are a vacation option that has been gaining more and more attention since the 90’s. This industry is currently undergoing a difficult situation due to the Covid pandemic, but once this situation is overcome, it is expected to
recover and continue providing an interesting vacation option for customers. Meanwhile, the growth of cruising activities during the last decades caused a saturation of Caribbean and Mediterranean regions, creating an interest in the industry for methods of selecting and creating new and optimized itineraries, the cruise ship itinerary design problem.

This paper presented an optimization model that returns the optimal itinerary route for a given set of ports. To do so, it takes as input information about possible ports of call and their attractiveness, size of the ship and its cost structure, and the desired duration of the itinerary. The optimal itinerary is defined by the one which has the highest profit. Commercial software CPLEX was used to code and solve this problem, in a few minutes in most cases.

A case study was carried out for the Atlantic Coast of the Iberian Peninsula, Morroco and Canary Islands. The analysis tried to identify whether there could be profit improvement for itineraries considering ports not traditionally served by cruise ships. Results for this case study showed that given a fixed itinerary duration, any changes on the ports served by the itinerary, good or bad, results in a direct increase or decrease of total profit. This happens because given a fixed itinerary length, differences of fuel consumption of the ship are minimal in comparison with including more valuable attractions in the itinerary.

Moreover, the results showed that, in the case of the Iberian Peninsula, there are opportunities for new routes, with expected increase in profits of more than $400,000 per weekly voyage, both during Winter and Summer season. On both seasons, the improved itineraries focused on the coast of Portugal, Spain, and Morocco.

Further work may be carried out by including important factors for the cruise itinerary such as the ports availability, the logistics of the food and the crews, improvements on the revenue and cost structure of the model. The revenue function can be improved by considering the departure and arrival time when calculating the attraction value of each destination instead of forcing the optimization model to stay a minimum number of hours at each destination. For the cost structure, values of manning, fuel, and port tax should consider the region of the world where the itinerary is located. Additionally, external costs such as environmental impact and social impact at the destinations could be included in the cost structure.

REFERENCES


