UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Human Movement Route Mapping: A Study in the Galapagos Islands

Claudia Fernanda Betancourt Ruiz

María Serena López Donoso

Jorge Esteban Salvador Duque

Ingeniería Industrial

Trabajo de fin de carrera presentado como requisito
para la obtención del título de
Ingeniero Industrial

Quito, 11 de mayo de 2020

Universidad San Francisco de Quito USFQ

Colegio de Ciencias e Ingenierías

HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA

Human Movement Route Mapping: A Study in the Galapagos Islands

Claudia Fernanda Betancourt Ruiz

María Serena López Donoso

Jorge Esteban Salvador Duque

Nombre del profesor, Título académico **Carlos Suárez, Ph.D.**

Quito, 11 de mayo de 2020

DERECHOS DE AUTOR

Por medio del presente documento certifico que he leído todas las Políticas y Manuales de la Universidad San Francisco de Quito USFQ, incluyendo la Política de Propiedad Intelectual USFQ, y estoy de acuerdo con su contenido, por lo que los derechos de propiedad intelectual del presente trabajo quedan sujetos a lo dispuesto en esas Políticas.

Asimismo, autorizo a la USFQ para que realice la digitalización y publicación de este trabajo en el repositorio virtual, de conformidad a lo dispuesto en el Art. 144 de la Ley Orgánica de Educación Superior.

Nombres y apellidos: Claudia Fernanda Betancourt Ruiz

Código: 00125412

Cédula de identidad: 1719207902

Lugar y fecha: Quito, mayo de 2020

DERECHOS DE AUTOR

Nombres y apellidos: María Serena López Donoso

Código: 00132030

Cédula de identidad: 1726518598

Lugar y fecha: Quito, mayo de 2020

DERECHOS DE AUTOR

Por medio del presente documento certifico que he leído todas las Políticas y Manuales de la Universidad San Francisco de Quito USFQ, incluyendo la Política de Propiedad Intelectual USFQ, y estoy de acuerdo con su contenido, por lo que los derechos de propiedad intelectual del presente trabajo quedan sujetos a lo dispuesto en esas Políticas.

Asimismo, autorizo a la USFQ para que realice la digitalización y publicación de este trabajo en el repositorio virtual, de conformidad a lo dispuesto en el Art. 144 de la Ley Orgánica de Educación Superior.

Nombres y apellidos:	Jorge Esteban Salvador Duque
Código:	00124729
Cédula de identidad:	1715847305
Lugar y fecha:	Quito, mayo de 2020

ACLARACIÓN PARA PUBLICACIÓN

UNPUBLISHED DOCUMENT

ABSTRACT

This work focuses on the study of human maritime movement within the Galapagos Islands. As they are one of the biggest marine reserves in the world it is important to have control of the maritime transport with the purpose of minimizing its impact in the islands. Historic data was gathered, verified and analyzed for the subsequent application of mathematical optimization models. The aim is to propose an improvement of the dynamic of the transportation in the Islands. Among the applied models there are variations of the Fleet Assignment Problem (FAP) and the Vehicle Routing Problem (VRP), specifically the Multi-Depot Vehicle Routing Problem (MDVRP) and the Multi-Depot Periodic Vehicle Routing Problem (MDPVRP). These ones were used as preliminary models in order to show optimal solutions regarding the maritime transport in the Islands.

Key words: Galapagos Archipelago; maritime transport; FAP; MDVRP; MDPVRP.

RESUMEN

El presente trabajo se centra en el estudio del movimiento humano marítimo inter-islas en el archipiélago de Galápagos. Al ser una de las reservas marinas más grandes del mundo resulta de gran importancia mantener un control del transporte marítimo, con el fin de que este tenga un impacto mínimo en el ecosistema. Se realizó una recopilación, verificación y análisis de datos históricos para la posterior aplicación de modelos de optimización que permitan un mejoramiento de la dinámica de transporte existente en las islas. Entre los modelos aplicados se encuentran variaciones del Problema de Asignación de Flotas (FAP) y del Problema de Ruteo de Vehículos (VRP), en concreto el Problema de Ruteo de Vehículos con Múltiples Depósitos (MDVRP) y el Problema de Ruteo de Vehículos Periódico con Múltiples Depósitos (MDPVRP). Los cuales han servido como modelos preliminares para demostrar soluciones óptimas con respecto al transporte marítimo en las Islas.

Palabras clave: Archipiélago de Galápagos; transporte marítimo; FAP; MDVRP; MDPVRP.

INDEX

TABLE INDEX

FIGURE INDEX

1. Introduction

Nowadays the need for policies that support the sustainable development of the countries has become crucial. More emphatically, in specific locations such as parks or nature reserves due to the high density of unique flora and fauna that needs to be protected. A clear example of this situation is the Galapagos archipelago, this place is considered one of the most biodiverse locations in the world. In 1978, the Heritage Committee of the United Nations Educational, Scientific and Cultural Organization (UNESCO) declared the Galapagos Islands - and later in 2001 the Galapagos Marine Reserve - as a Natural World Heritage Site (Galapagos National Park Directorate, 2019). There are more than 43,000 species of plants, 998 species of vertebrate animals and 45,000 species of invertebrates (CDF, 2017). The Archipelago is compound of seven major islands (Isabela, Santa Cruz, Fernandina, Santiago, San Cristóbal, Floreana y Marchena) and fourteen minor islands (Española, Pinta, Baltra, Santa Fé, Pinzón, Genovesa, Rábida, Seymour Norte, Wolf, Tortuga, Bartolomé, Darwin, Daphne Mayor y Plaza Sur) (Galapagos National Park, 2019). On a global scale, maintaining high-density biodiversity locations under protection is critical to the planet's environmental conservation.

A fundamental part of the sustainability of the Islands lies in the interaction between people and the ecosystem. Within this relationship, transportation plays a crucial role (Galapagos National Park Directorate, 2019). Inside the Galapagos islands the human movement transportation is divided into two main systems: maritime and air travel. The first one involves the greatest amount of movement in the Archipelago (Galapagos Tourism Observatory, 2019). Due to this fact, the focus of this study will be on maritime transportation, which is divided as well into two different categories: public and tourist transportation.

On the one hand, residents mainly use public transportation as a form of mobilization between the 4 inhabited islands: Isabela, Santa Cruz, San Cristóbal and Floreana (Ecuadorian Undersecretariat of Ports, 2020). The price of the inter-island trip is set at USD 30 by the Undersecretariat of Ports, making this the most expensive inter-cantonal ticket in the country (Ecuadorian National Transit Agency, 2019). Despite its high costs, sea transportation is the most economical alternative compared to air travel. The appearance of increasingly fast motorized watercrafts has made it easier for residents to reach different islands in the Archipelago to visit family members and satisfy their need to supply goods, which are often limited (Guyot-Téphany, et. al., 2011).

On the other hand, tourists choose to move to inhabited and uninhabited Islands. Galapagos National Park approved tourism operations include navigable cruise tour, navigable diving tour, daily tour, daily diving tour, bay tour, vivencial fishing and port-to-port tour (Galapagos National Park Directorate, 2019). The flow of tourists has increased significantly in recent years, as they travel from one Island to another daily (Galapagos National Park Directorate, 2019). In fact, in 2018 the Islands welcomed the highest quantity of tourists (276,000) since 1980, the year tourist registration started (Galapagos Tourism Observatory, 2019).

It is known that human movement between Islands increased by 14% between 2017 and 2018 (Galapagos Tourism Observatory, 2019), an increase that threatens to exceed the Carrying Capacity of the Islands (maximum number of people an ecosystem can sustain without degrading it) (Ellie Maclin, 2018). Despite the great need now there are neither complete nor current statistics that fully show the behavior of human flow movement between the Islands.

Most of the data regarding the Galapagos transportation system is not available for public access. Therefore, the aim of this study is to understand inter-island and continentisland human mobility flows by collecting updated transport data in order to carry out a preliminary model of route optimization to reduce environmental impact.

2. Literature Review

For the literature review different papers were reviewed. The main feature sought in the papers was the use of optimization tools for transport systems that resemble those existing in the Galapagos Islands. Sources such as Scopus, ScienceDirect and Research Gate were used to search for the papers.

Data analysis

Several studies use databases and data mining to obtain information on archipelagos including vessel movements and the human transportation involved in it. Hatziioannidu and Polydoropoulou (2016) use the information generated by the cellphones within the Aegean archipelago. It recollects the GPS information that is emitted and tracks it within the Islands. This information allows to observe which are the routes, ports, places of interest and movement demand at each of the Islands. Then it is possible to generate a gravity model that allows to predict how many people will arrive at each of the Islands (Hatziioannidu and Polydoropoulou, 2016). Another study conducted by Maragoudakis (2018) focuses on collecting various types of historical information in order to bring it together and use it to generate an optimization model and visualization tools to help experts in the maritime field generate policies, regulations and emergency plans (Maragoudakis, 2018). The development of the research mentioned is carried out in two sections. The first focuses on the collection and processing of existing data on the maritime mobilization of the Aegean archipelago. The second part is dedicated to the processing, simulation and visualization of the data gathered (Maragoudakis, 2018). A Clustering Algorithm was used to process and organize the information obtained, the simulation used Bayesian networks and Social Network Analysis was used for visualization (Maragoudakis, 2018).

Kim and Lee (2019) have a different perspective on the usage of databases to improve shipping routes. In their study they use the Automatic Identification System (AIS) (an automated tracking system that broadcast the vessel live coordinates to a global server) to collect the information; however, the volume of information is so large that it is virtually impossible for control authorities to understand what is presented on the screens, so the study is dedicated to filter the relevant information to solve this problem (Kim and Lee, 2019). Another research that takes advantage of AIS technology is the one proposed by Andersson and Ivehammar (2016). In his study the authors use this technology intending to verify capacity limitations and route structures to optimize them by reducing transportation costs as well as fuel consumption (Andersson and Ivehammar, 2016).

Mathematical models

Since the 1990s, route optimization and planning models have become increasingly accurate due to advances in computer capacity (Alexandre et al, 2019). In this context, numerous studies have been presented regarding sea route optimization models. Within the literature reviewed, two main types of models can be found that are used to solve shipping routes optimization problems: models with a heuristic approach and models with an exact approach. Within these mathematical models there are several that are used to determine maritime transportation flows, both for cargo ship movement as well as for passenger ships. These include variants of the Travelling Salesman Problem (TSP), the Maritime Inventory Routing Problem (MIRP) (De et al, 2017) and even models focused mainly on pollutant emissions such as the green vehicle routing and scheduling problem with soft time window (GVRSP-STW) (Chen et al., 2020). In case the routes are already defined, many researchers use the Fleet Assignment Problem (FAP). This problem considers constraints of the fleet, the vehicles and the routes available (Sherali, Bish and Zhu, 2005). Thus, the model assigns the number of vehicles that must take a specific route, optimizing the resources and complying with the constraints presented. Many of the applications of this model are developed in airlines since it adapts very well to the conditions that this sector presents (Li and Tan, 2013). However, one of the most widely used models is the vehicle routing problem (VRP) and its respective variants.

The objective of the vehicle routing problem (VRP) model is to find the best route that minimizes the cost, or distance travelled, taking into account that there is a fleet of vehicles with the same capacity that start at a central depot and have to serve all the customers. As well as other constraints like the one establishing that the demand has to be satisfied (Juliandri1, Mawengkang & Bu'ulolo, 2018). As mentioned before, there are several variants of this type of model. Among them is the capacitated vehicle routing problem (CVRP) where the capacity of the vehicle is also considered and taken as a model restriction (Kır et al., 2017). Besides the CVRP there is the MDVRP, or Multi Depot Vehicle Routing Problem, where the model is restated considering a situation of having more than one starting node, or so-called depot, from where the fleet of vehicles depart (Surekha & Sumathi, 2011). Another existing variant can be seen in Hu's (2018) work which relies on VPR to formulate a model of maritime transport that can divide existing demand into different vehicles, and it is known as a split delivery vehicle routing problem (SDVRP).

Although there are several models used to conduct studies related to maritime transport, not all of them take into account the itineraries that passenger vessels must follow or other restrictions involving human transport, such as the time that the vessel must remain in port for all passengers to enter or leave. Because of this, other models have been developed that consider these types of constraints and are therefore more applicable to the analysis of human transportation. Among these models is the vehicle routing problem with time windows (VRPTW), which is a variant of the vehicle routing problem (VRP) but, as its name indicates, considers time windows that must be met by the vehicle on the routes it must cover (El-Sherbeny, 2010). Another model that takes into account the time is the periodic vehicle routing problem (PVRP). This model considers a time horizon that the vehicles have to cover while satisfying the usual constraints of the VRP (Coene, Arnout & Spieksma, 2008).

Mancini and Stecca (2018) also proposed a variant to the vehicle routing problem (VRP) based on a matheuristic that emerges from the Large Neighborhood Search (LNS), where it is considered the route followed by most boats within the Islands and even restrictions of the ports, such as time or boat crossings; which fits better to the reality of human flow in the Archipelago.

Taking into account the different mathematical models proposed by the authors mentioned above, the present study introduces different models that are variants of the Fleet Assignation problem and the VRP. These models have been developed in order to satisfy the transport situation of the Galapagos archipelago.

3. Methodology

The main interest of this work is to generate a preliminary mathematical model of the inter-island movement of passengers along the Galapagos Islands. Because of that, the methodology that this project will follow is the one proposed by Hillier and Lieberman (2015). This methodology involves 6 different phases:

Phase 1: Defining the problem and gathering data.

Phase 2: Formulating a mathematical model to represent the problem.

Phase 3: Developing a computer-based procedure for deriving solutions to the problem from the model.

Phase 4: Testing the model and refining it as needed.

Phase 5: Preparing for the ongoing application of the model.

Phase 6: Implementing.

(Hillier and Lieberman, 2015)

However, due to the extension of this project, only the first three phases of the methodology have been developed. These phases are described in the following sections.

3.1 Defining the problem and gathering data.

This first phase will be fully detailed in section number 4 and it will examine the actual situation of inter-island movements between the Galapagos Islands in order to establish what are the main issues that should be covered in order to optimize the existing shifts, between the islands. With that in mind, it will be possible to determine which variables, restrictions and limitations the project has to consider in order to clearly know all the data that should be gathered and what information has to be excluded. As Hillier and Lieberman stated, gathering data can be an overwhelming task (2015). Because of that, it is important to determine the main sources of data. Among the digital formats are those provided by the Galapagos Tourism Observatory, the Ministry of Environment of the Republic of Ecuador, the Galapagos National Park and the Ecuadorian National Institute of Statistics and Censuses (INEC). Besides these, other important information will be gathered in-situ, visiting the Galapagos Islands and approaching the government organizations that operate in the Islands. Some of them include public transportation services, the port captaincies, the Undersecretariat of Ports and the Galapagos National Park. It is known that these organizations have information regarding the sailing of the vessels registered on each Island, the routes and the timetable permissions given to all of them. It is important to mention that each captaincy has information only of the Island that they are in charge of, and the institution that gathers the information of the whole archipelago is the National Direction of Aquatic Spaces (DIRNEA for its Spanish acronym) located in the city of Guayaquil.

3.2 Formulating a mathematical model

For this phase, that will be developed in section 5, the decision variables, restrictions, parameters and objective function of the model will be determined. The aim of this model is to show the current situation of the Islands. (Hillier and Lieberman, 2015). Also, this phase is important because it allows a better understanding of the relationship of the current situation and the previously gathered data. (Hillier and Lieberman, 2015). It is also important to mention that the models will provide an output variable that is relevant to the research and will allow to draw preliminary conclusions (Hillier and Lieberman, 2010).

3.3 Developing a computer-based procedure for deriving solutions to the problem from the model.

As previously mentioned, this third phase will be the last one covered in the study in section 6. This step consists on finding a solution using the mathematical model formulated on the previous phase with all the relevant information gathered on the first phase. The software that will be used to run the established models is AMPL (A Mathematical Programming Language). According to Hillier and Lieberman (2010), the results obtained seek to meet an optimal solution and must fulfill the requirements and constraints established. In case the optimal solution cannot be obtained due to reasons beyond the control of the researchers, then concessions will be made to obtain a sub-optimal solution (Hillier and Lieberman, 2010).

4. Defining the problem and gathering data

The maritime transportation in the Galapagos archipelago is divided into two segments: public and touristic. According to the information gathered from the Undersecretariat of Ports (2019) and the Galapagos National Park (2020), from the total of vessels in the Galapagos Islands, 85% belong to touristic transportation and the rest to public transportation. Both of these divisions are described next.

4.1 Public maritime transportation

The first section of inter-island transportation in Galapagos belongs to the public sector. This transportation involves the vessels that cover routes between the inhabited islands of the Archipelago that include Santa Cruz, San Cristobal, Isabela and Floreana, according to the 2015 census (INEC, 2015), as Figure 1 illustrates. It is necessary to clarify that the name of the city within each Island is acquired from its main port. Hence, Puerto Baquerizo Moreno is located in San Cristóbal, Puerto Ayora in Santa Cruz, Puerto Villamil in Isabela and Puerto Velasco Ibarra in Floreana.

The problems that involve this type of transportation are complex. First, depending on the season, the waiting time in the departure ports tend to be longer due to the passengers' affluence. On the opposite side, some of the ships travel underutilized due to the lack of demand in the low season. Related to this problem is the fact that there is not a minimum number of passengers established for the vessels to cover a certain route. From an interview with the president of one of the two cooperatives of maritime transporters in the Archipelago, if only one passenger pays for a trip from one Island to another then the boat is obligated to provide the service (Sotomayor, Transgal Cooperative President, 28/02/2020). Hence, it is not always convenient to make the trip due to the costs involved. The daily operating cost is about USD 500 while the turnaround time in port costs USD 2.50 per day (Sotomayor, Transgal Cooperative President, 28/02/2020). This is due to the high gasoline consumption of the boats used in public transportation. Finally, vessels expel polluting gases mainly Nitrogen oxides (NO_x), thus contributing to the environmental changes and causing damage to the flora and fauna of the Islands (Latarche, 2017).

Figure 1. Routes Between Populated Islands

Once the problems of the public maritime transportation have been stated the next step of this phase focuses on gathering the data in order to determine a possible improvement of the current situation. It is necessary to clarify how the public transportation works in the Galapagos' Archipelago. Passenger vessels, whose maximum capacity range from 18 to 35 seats, require two main documentations in order to perform their daily operations. The first one is the operating license issued by the Undersecretariat of Ports and the second one corresponds to the Departure of the vessel (*Zarpe*), a sample of this document is shown in Appendix 1. The last one, on the other hand, is issued by the corresponding Port Captaincy depending on the Island from where the vessel is departing. Once the vessels have the respective permits, they are cleared to travel from one Island to another within the established routes and schedules.

There are nine routes approved by the Undersecretariat of Ports that focus just on the connection between the main Islands, although, only five of them are used nowadays (Ecuadorian Undersecretariat of Ports, 2019):

Table 1. Public transport routes

Number	Routes
1	San Cristóbal - Santa Cruz - San Cristóbal
2	Santa Cruz - San Cristóbal - Santa Cruz
3	Isabela - Santa Cruz – Isabela
4	Santa Cruz - Isabela - Santa Cruz,
5	Santa Cruz - Floreana - Santa Cruz

It is possible to see that the routes cover a round trip, meaning that the vessels must return to their departure port once they have finished the route. In order to do this, the vessels have an established schedule that must be followed. Each vessel must leave the first port in the morning, between six and eight a.m. depending on the route covered, and must return around three p.m. According to the Undersecretariat of Ports, 31 vessels have the operating license that limits each vessel to a single route, excluding the ferries that are part of Transmartisa cooperative since they get to cover the five routes (Ecuadorian Undersecretariat of Ports, 2019). The information gathered has shown that the most common route is number four (Figure 2) and that the vessels with the highest capacity are the ones that follow route number 1.

Figure 2. Vessel per Route

Furthermore, the Departure of the vessel is a mobilization authorization that records every movement carried out by the ships. This document contains information about the vessel's name, the registration plate, the entry and exit ports and the day and time of the departure (Alarcón, 2015). Attached to the report mentioned it is included a handwritten list of all the passengers, however, this information is never digitalized. Due to this fact, the data about the number of people that travel from one Island to another per month will be taken from the Galapagos Tourism Observatory 2018 databases.

4.2 Tourist maritime transportation

The tourist maritime transportation is the second division of the inter-island human maritime movement. This transportation, unlike the public one, involves the movement between inhabited and uninhabited Islands because the purpose is that the people, mainly tourists, get to visit the different locations and habitats of the Archipelago, exploring one of the most biodiverse ecosystems in the world. This transportation involves similar problems as the public one but in different scales and contexts. First, as mentioned before, this kind of transportation has as its primary users' foreigners that are visiting Galapagos. Due to that, there are more changes on the demand as seasonality plays an important role here. However, and as a second problem too, there is the fact that this kind of transportation is managed by private companies, mainly tourist agencies, so they are on their right to decide whether their vessel or vessels will be available for transportation along the Islands or not. Third, and just like for the public transportation, these vessels are an important source of pollution to the ecosystem, emitting Nitrogen oxides (NO_x), gases that come from the oil burnt of the engines (Latarche, 2017).

Despite the problems mentioned, this type of transportation has an important place on the Galapagos Islands. Similarly, as the public transportation, the vessels also need certain documents to operate on the archipelago. The first document that the vessels, within this category of human maritime movement, need is the operation patent that is issued by the Galapagos National Park (Appendix 2). This document contains information about the vessel, its name, the name of the company or operator that it belongs to, the operation modality, the capacity, the itinerary they are allowed to follow, between other things. The current operation modalities are the ones depicted in Table 2, with the respective percentage of vessels in that category in 2020. Regarding the itinerary, the operation patent shows a list of the places that the vessel is authorized to visit and the days they are permitted to go to each one. The document also shows the activities that are permitted to be done at each place. These activities include scuba diving, snorkeling, kayaking and panga rides. On the other hand, the second document needed is the Departure of the vessel (Appendix 1). This last one is the same as the one the vessels that cover the public transportation need. It states the name of the vessel, its registration plate, the exact day and ports of the departure and arrival.

Table 2. Operation Modalities for tourist transportation

Operation Modality	Percentage of vessels
Navigable cruise tour	41%
Vivencial fishing	26%
Daily diving tour	13%
Bay tour	8%
Daily tour	7%
Navigable diving tour	5%
Port-to-port tour	0%

Knowing the information of the tourist transportation it was possible to look for all the data regarding the actual situation. Among the data gathered, there is a list of the vessels that had obtained an operation patent in 2020 from the Galapagos National Park (Appendix 3) (Galapagos National Park Directorate, 2019). From this, it was possible to know the service type of each vessel, therefore the number of vessels per category (Figure 3); as well as the average passenger quantity per service type (Figure 4).

Figure 3. Number of vessels per type of service

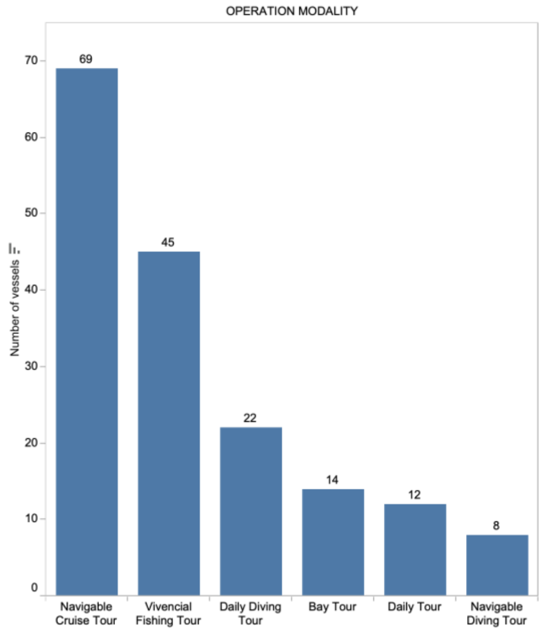
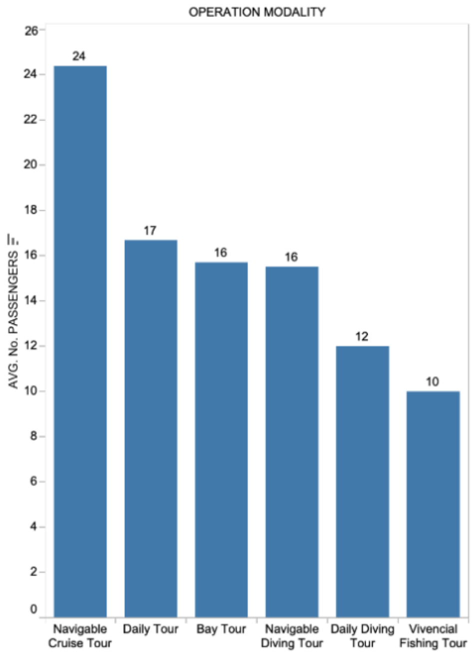


Figure 4. Average passenger capacity per type of service



In order to determine the list of places that all the vessels are going through, it is necessary to have the operation patent for each vessel. However, as the updated operation patent of each vessel could not be obtained due to the long and restrictive processes of the institutions involved, it was only possible to gather information from operation patents corresponding to 2010 (Galapagos National Park Directorate, 2016).

With the list of vessels that obtained an operation patent on 2020, the operation patents of the vessels serving on 2010 and the historical record of vessel sailings from 2019 obtained from the Port Captaincies, it was possible to go through a data mining process with the purpose of checking which vessels are still operating and which are the places that they have been authorized to visit on their itineraries.

Finally, with all the information processed the data that will be used on this project regarding the tourist maritime transportation corresponds to 33 vessels, 34 visiting locations, and 4 departure ports, depicted in Appendix 4, 5 and 6 respectively. With these data the next step was to estimate the distance travelled between all the visiting points and from each port to each location. However, due to limitations during the study the distances used were the Euclidean distances between all the points considered. Hence a matrix of 1444 records was obtained which is shown in Appendix 7.

5. Model Formulation

As aforementioned in the literature review there are many models that can be applied to the reality of the transport system in the Galapagos Archipelago. However, due to the differences between the public and tourist maritime transportation this section will be divided into two different parts, focusing on each one of these two divisions.

5.1 Public maritime transportation

Regarding the public maritime transportation two models have been formulated. The main purpose is to have a better understanding of the situation and to create a more efficient way of movement between the four main Islands.

5.1.1 Fleet Assignment Problem

For the first optimization model, the current situation of the public transportation mentioned on the last section was considered. An adaptation of the fleet assignment problem (FAP) was created based on the main assignment problem (Singh, Dubey and

Shrivastava, 2012). This model was chosen because it fits accurately to the current situation of the Islands, taking into account that there are established routes and vessels that perform this activity. The FAP seeks to allocate vessels in the most efficient way so that the available resources are used in the best way (Li and Tan, 2013). For this adaptation, the objective function (1) is set to reduce the overall operating cost of the system by optimizing the assignment of vessels to a specific route.

The mathematical formulation:

$\boldsymbol{Sets}$:

$K\ is\ the\ sets\ of\ vessel$

$R\ is\ the\ sets\ of\ routes$

$\boldsymbol{Parameters}$:

$C_{ik}: traveling\ cost\ of\ vessel\ k\ in\ route\ r;$

$Q_k: Capacity\ of\ vessel\ k$

$A_{ik}: assignment\ of\ route\ r\ to\ vessel\ k$

$D_r: Demand\ of\ route\ r$

$\boldsymbol{Variables}$:

$x_{ik}: binary, 1\ if\ vessel\ k\ crosses\ route\ r$

$y_{ik}: integer, the\ number\ of\ people\ travelling\ in\ vessel\ k\ in\ route\ r$

$$Min\ Cost: \sum_{i \in R} \sum_{k \in K} C_{ik} x_{ik} \qquad (1)$$

$$x_{ik} \leq A_{ik}, \quad \forall\, i \in R, \forall\, k \in K \qquad (2)$$

$$\sum_{k \in K} y_{ik} x_{ik} \geq D_i, \quad \forall\, i \in R \qquad (3)$$

$$Q_k \geq y_{ik} x_{ik}, \quad \forall\, i \in R, \forall k \in K \qquad (4)$$

$$\sum_{i \in R} x_{ik} \leq 1, \quad \forall\, k \in K \qquad (5)$$

$$\sum_{k \in K} x_{ik} \geq 1, \quad \forall\, i \in R \qquad (6)$$

Constraint (2) guarantees that each vessel is only assigned to its respective route. Constraint (3) guarantees that the demand is satisfied. Constrain (4) guarantees that the capacity of the vessel is not exceeded. Constraints (5) and (6) guarantees that a maximum of one arc can enter and leave each vertex.

5.1.2 Multi-Depot Vehicle Routing Problem

In addition to the current state of the archipelago's maritime transport system (AS-IS), the creation of a new route planning scenario for the vessels was also considered (TO-BE). In order to do this, a variation of the VRP (Vessel Routing Problem) was used. The MDVRP (Multi-Depot Vessel Routing Problem) focuses on serving several clients from several depots, in this case, serving the arrival ports from the departure ports (Ramos, 2019).

The objective of this new mathematical formulation is to create route sequences that ensure that the use of resources is minimized. Meeting the demands of the ports of arrival and the capacities of the vessels and other constraints are considered.

The mathematical formulation for the model proposed for the new scenario is:

$\boldsymbol{Sets}$:

$DP\ is\ the\ vertices\ of\ departure, departure\ port\ for\ vessels;$

$AP\ is\ the\ vertices\ of\ arrival, visiting\ points;$

$N\ set\ of\ all\ vertices\ (DP \cup AP);$

$K\ set\ of\ all\ vessels;$

$\boldsymbol{Parameters}$:

$C_{ij}: traveling\ distance\ between\ vertex\ i\ and\ vertex\ j;$

$Q_k: Capacity\ of\ vessel\ k;$

$D_j: Demand\ of\ vertex\ j;$

$Kd_{ik}: vessel\ k\ belonging\ to\ port\ i\ in\ DP;$

$\boldsymbol{Variables}$:

$x_{ijk}: binary, representing\ the\ route\ solution: 1\ if\ vertex\ \ j\ is\ visited\ immediately\ after\ vertex\ i\ by\ vessel\ k;$

$y_{ijk}: integer, the\ number\ of\ people\ travelling\ in\ vessel\ k\ from\ vertex\ i\ to\ vertex\ j;$

$z_{ijk}: binary, assigning: 1\ if\ vertex\ \ i\ is\ visited\ by\ vessel\ k;$

$$Min\ Dist: \sum_{i \in N} \sum_{j\ in\ N} \sum_{k\ in\ K} x_{ijk} C_{ij} \ \leq 1 \qquad (1)$$

$$\sum_{i \in DP} \sum_{j \in AP} x_{ijkp} Q_k \geq D_j, \quad \forall\ k\ \in\ K, \forall\ p\ \in P \qquad (2)$$

$$\sum_{i \in DP} \sum_{j \in AP} x_{ijkp} \leq 1, \quad \forall\ k\ \in\ K \qquad (3)$$

$$\sum_{j \in DP} \sum_{i \in AP} x_{ijkp} \leq 1, \quad \forall\ k\ \in\ K \qquad (4)$$

$$x_{ijkp} = x_{jikp}, \quad \forall\ i \in DP, \forall\ j \in AP, \forall k \in K \qquad (5)$$

$$\sum_{j \in AP} x_{ijkp} \leq K d_{ik}, \quad \forall\ k\ \in\ K, \forall\ i\ \in DP \qquad (6)$$

The objective function (1) focuses on minimizing the overall distance traveled by the entire system. As a result, the use of resources to enable costumers reach their destinations is reduced. Constraint (2) ensures that the outgoing flow from the ports is equal to the demand from each of the visiting points. Constraint (3) and (4) guarantee that a vessel can only arrive to a point and it can only leave such point in each of the trips. Constraint (5) guarantees that the same vessel that travels through a route is the same vessel that returns on such route. Finally, constraint (6) guarantees that the vessels that are deployed belong to a specific departure port and not to an arriving port.

5.2 Tourist maritime transportation

As explained above, the Galapagos' transportation system is divided into two sections. Like the public transport system, the tourist transportation system was also analyzed. An optimization model was created using the Multi-Depot Periodic Vessel Routing Problem, which focuses in serving many clients starting from different depots in a specific period (Cantu-Funes et.al, 2017). This variation of the VRP was chosen because it incorporates the use of several departure depots, a crucial characteristic for this kind of transportation because it is necessary to consider all the departure ports for the vessels.

However, during the developing of the model several constraints were adapted in order to fit the model into the reality of the tourist system.

Sets:

$VP\ set\ of\ visitng\ points$;

$DP\ set\ of\ departure\ ports$;

$N\ set\ of\ total\ number\ of\ vertices$;

$A = \{N, N\}\ set\ of\ arcs\ formed\ between\ N$;

$K\ set\ of\ vessels$;

$P\ set\ of\ traveling\ periods$;

Parameters:

C_{ij}: $traveling\ distance\ between\ vertex\ i\ and\ vertex\ j$;

Q_k: $Capacity\ of\ vehicle\ k$;

D_i: $Demand\ of\ each\ port$;

CC_j: $Carrying\ capacity\ of\ the\ islands$;

Variables:

x_{ijkp}: $binary, representing\ the\ route\ solution$:

$1\ if\ vehicle\ k\ crosses\ from\ vertex\ i\ to\ vertex\ j\ in\ period\ p$;

y_{ijkp}: $integer, the\ number\ of\ costumer\ travelling\ in\ vessel\ k$

$from\ vertex\ i\ to\ vertex\ j\ in\ period\ p$;

$$Min\ Dist: \sum_{p \in P} \sum_{i,j \in A} \sum_{k \in K} x_{ijkp} C_{ij}, \tag{1}$$

$$\sum_{p \in P} \sum_{i,j \in A} \sum_{k \in K} Q_k x_{ijkp} \geq D_i, \qquad \forall\ i\ \in DP, \forall\ k \in K \tag{2}$$

$$\sum_{i,j \in A} \sum_{k \in K} \sum_{p \in P} y_{ijkp} \leq Q_k x_{ijkp}, \tag{3}$$

$$\sum_{j \in N} \sum_{k \in K} \sum_{p \in P} y_{ijkp} \geq 100, \qquad \forall\ i\ \in DP \tag{4}$$

$$\sum_{i \in DP} \sum_{j \in VP} X_{ijk1} = 1, \qquad \forall\ k \in K \tag{5}$$

$$\sum_{i\in VP}\sum_{j\in DP} X_{ijk14} = 1, \qquad \forall\, k \in K \tag{6}$$

$$\sum_{i\in VP}\sum_{j\in VP} X_{ijkp} \leq 1, \qquad \forall\, k \in K, \forall p \in P \setminus \{1{,}14\} \tag{7}$$

$$\sum_{i\in N}\sum_{p\in P} X_{ijkp} \leq 1, \qquad \forall\, j \in N, \forall k \in K \tag{8}$$

$$\sum_{j\in N}\sum_{p\in P} X_{ijkp} \leq 1, \qquad \forall\, i \in N, \forall\, k \in K \tag{9}$$

$$\sum_{i\in VP}\sum_{j\in DP} X_{ijkp} = 0, \qquad \forall\, k \in K, \forall\, p \in P \setminus \{14\} \tag{10}$$

$$\sum_{i\in DP}\sum_{j\in VP} X_{ijkp} = 0, \qquad \forall\, k \in K, \forall\, p \in P \setminus \{1\} \tag{11}$$

$$\sum_{i,j\in A}\sum_{p\in P} X_{ijkp} \geq 1, \qquad \forall\, k \in K \tag{12}$$

$$\sum_{i\in N} x_{ihkp} = \sum_{j\in N} x_{ijkp+1}, \quad \forall\, k \in K, \forall h \in VP, \forall p \in P \setminus \{14\} \tag{13}$$

$$\sum_{i\in N}\sum_{k\in K} Q_k x_{ijkp} \leq CC_j, \qquad \forall\, j \in VP, \forall\, p \in P \tag{14}$$

The target function (1) ensures that the distance covered by the active vessels is minimized. Constraint (2) ensures that the demand is met and the constraint (3) ensures that the number of people sent in the vehicles do not exceed the capacity of the vehicles. Constraint (4) allows the variable of number of people to be activated. Constraints (5) and (6) guarantees that vehicles in periods 1 and 14 may only depart from and arrive at one port respectively. Constraint (7) ensures that there is no more than one connection made by the same vessel. Restrictions (8) and (9) ensure that sites are only visited once. Similarly, restrictions (10) and (11) ensure that vessels do not visit the ports except when it is the departure and arrival of the vessels. The restriction (12) ensures that at least one route is met for each vessel. The restriction (13) ensures that the visiting point of arrival of a boat is the same point of departure for the next period. Finally, constraint (14) ensures that the permissible load capacity for each point of visit is not exceeded.

6. Results and Discussion

This section is focused on the development of the third phase of Hillier's and Lieberman's methodology. Here, the three models mentioned on the previous section are taken into a computer-based procedure in order to obtain the results for each case and have a more efficient scenario that could optimize the human transportation in the Galapagos Islands. The computational software used, as mentioned before on this work, is AMPL. Below, there are two sections regarding the two existing cases: public and touristic transportation between the inhabited Islands.

6.1 Public maritime transportation models result

On the previous section it was mentioned that public maritime transportation was divided into two different models. For the following models, it is assumed an estimated average demand obtained from projections based on the 2018 demand collected from the Tourism Observatory data bases. These projections were calculated by applying the population growth formula, with a rate of 14%. This number was obtained from the percentage of demand growth on 2018 from the Tourism Observatory (2019). In addition, it is considered that all vessels are available, and that each one can only follow one route.

The main purpose was to have a better understanding of the actual situation of this type of transportation, optimizing the number of vessels that should perform the routes that are allowed. However, it also seemed relevant to implement a model that shows a better set of routes that the vessels should follow taking into consideration the demands at each port, with the purpose of optimizing the public transportation.

The first model implemented for the public transportation was a Fleet Assignment Problem (FAP). This model considers the 31 vessels that had been authorized in 2019 to use the five existing routes listed on Table 1. The vessels are listed on Appendix 8 with their respective capacities. It is important to mention that as the route covers a round trip between the Islands, in the model the capacities listed on were duplicated in order to establish the number of people that can go in the vessel from either of the ports involved in the route. Besides that, from the information provided by the Undersecretariat of Ports, it is known that each vessel covers a specific route. The information of the vessels and its respective routes is described in Appendix 9.

As mentioned in section 4.1, the operating cost of each vessel is approximately USD 500 per route covered. With that data it was possible to create a matrix establishing the cost for each route Appendix 10. For modeling purposes, regarding the distance between the same points a large scalar was used to disable that connection to be chosen. Besides the distance, the demand was taken into account in the model. It was obtained from the Galapagos Tourism Observatory (2018) and it is listed on Appendix 11. With all the information above, the model was run on AMPL using the solver Gurobi.

The results obtained are, first of all, the number of vessels that should be performing the routes for the public transportation, which route each of the vessels covers and how many people are travelling. The results will show the number of people that are traveling in the round trip. These results are shown in Table 3. It can be seen that the optimal number of vessels is 18 and that most of the vessels are travelling at their full capacity. Second of all, the model shows the total cost incurring the number of vessels that should be the ones covering the demand on the ports. The actual situation of the public transport, as mentioned before, involves 31 vessels, each one covering a route. As each route has an operating cost of USD 500 this means that with 31 vessels the total cost is $15 500. With the optimization model, as the number of vessels needed was reduced, with 18 vessels the total cost is $9 000. This shows a reduction of $6 500 per day for the total operating costs of this type of transport in the Islands.

Table 3. Fleet assignation model results

Vessel Name	Number of people travelling on a round trip	Route Covered
ARRECIFE	66	1
GALAPAGOS OSPREY	70	1
GALAPAGOS PRIVILEGIO	47	1
ANDY II	56	2
GEMA	56	2
TROPICAL BIRD	56	2
GABI	26	3
GLADEL	48	3
NEPTUNO I	46	3
ANGY	58	4
BRITHANNY I	52	4
CALLY I	60	4
EL MANGLE	68	4
NEPTUNO	60	4
NEW BRITHANY	37	4
SOLMAR	56	4
SPLENDOR I	60	4
QUEEN ASTRID	38	5

The second model implemented for the public transportation in the Galapagos Islands was a Multi-Depot Vessel Routing Problem (MDVRP). The objective of this model is to see if there is an optimal set of routes that can satisfy the actual situation. For this model, the input information needed was the following.

First of all, the departure and arrival ports. Here it is important to mention that for modeling purposes, as each route involves a round trip this means that the departing port is going to be visited two times. This port is the one from where the vessel starts the route covered and it is the one at which the vessel needs to return to in order to finish the route.

The next information needed is which vessels are assigned to each of the ports, shown in Appendix 12. The information about the vessels' names and capacities, also used on the previous model, is shown in Appendix 8. Besides that, this model considers the distance between the ports, depicted in Appendix 7 and the demand of each port shown in Appendix 11.

With all this information it was possible to run the model using AMPL with the solver Gurobi. It takes a few minutes to return an answer to the applied model. The results obtained show the new routes that should be considered in the Archipelago and which vessels should perform them. These results are shown in Table 4, where the numbers of vessels correspond to the ones listed in Appendix 8.

The results show that in addition to the routes already established, two more routes could be implemented with the aim of meeting the demand. The first proposed route (6) is the one that goes from San Cristóbal to Floreana and back and the second proposed route (7) is the one that leaves from Floreana, goes to Isabela and back. It should be noted that Route 6 has already been approved by the Undersecretariat of Ports but it is not in force. On the other hand, Route 7 is not included in the list of approved routes, so its implementation could be more complex. Even though these results suggest the best routes that the vessels designated for the public transportation should perform, it has to be considered that putting in practice this model in the Islands can be difficult. There are quite a few companies involved in this type of transportation, as well as institutions in charge of all the regulations needed in the archipelago. However, it seemed important to show that there is a better combination of routes that can satisfy the demand on the four inhabited Islands.

Table 4. MDVRP model results

	Route	**Vessel**
1	San Cristóbal - Santa Cruz - San Cristóbal	6,14,31
2	Santa Cruz - San Cristóbal - Santa Cruz	2,7,10,15,22,28,30
3	Isabela - Santa Cruz - Isabela	12,16,20
4	Santa Cruz - Isabela - Santa Cruz	3
5	Santa Cruz - Floreana - Santa Cruz	4,5,8,9,18,19,21,25,26
6	San Cristóbal - Floreana - San Cristóbal	13
7	Floreana - Isabela - Floreana	23

6.2 Tourist maritime transportation model results

The tourist maritime transportation was modeled using the multi-depot periodic vessel routing problem as mentioned before on this work. In order to apply this model on a computer-based software, it is necessary to detail all the data used. First, The following assumptions were made: each vessel must visit two points per day, a tour lasts 7 days, the departure from the port takes place during the first day and the arrival during the last day, all touristic places must be visited at least once and finally, the distance between places is linear. Also, as mentioned on section 4.2, the number of vessels that are going to be taken into consideration for this study is 33, due to the limited information obtained. According to the patents of operation these vessels have a certain capacity that must also be considered. All of this information about the vessels is listed in Appendix 4. As it was also stated early, the patent of operation that these vessels require in order to perform their activities includes a list of places that there are allowed to go to each day. This information is called the itinerary and includes the days and times in the day that there are allowed to visit those places. Due to the information obtained, the total visited places that are going to be considered for this preliminary model are the ones listed in Appendix 5.

Besides the general information stated in the previous paragraph, the model also requires other data in order to run. The first thing to consider is the distanced traveled between touristic places, this distance between all the points considered was mentioned previously at the end of section 4.2 and it is shown on Appendix 13. It is important to make it clear that this model is considering four depots, in other words, four starting points from where the vessels must start the trip and where they must end. However, vessels cannot travel from depot to depot, that is why in the matrix shown in Appendix

13 the distances within these points was declared with really high values, so the model does not consider going through these arcs.

There are some other important values that were considered on the model. For starters, the carrying capacity of the visiting places. This value indicates the number of people that can visit each touristic place considering its area and its physical conditions. This information was obtained online through documents of the Galapagos National Park (2016) and Amador et. al. (1996). The Islands have a specific carrying capacity that is measured either in groups per day or groups at the same moment. For this model, the information taken was the number of groups per day allowed. However, as the units used in the model is the number of people, the carrying capacities were transformed from the number of groups into the number of people allowed, considering that each group is formed by 17 people, 16 tourists and a guide (Amador et. al., 1996). With that in mind, Appendix 5 shows the number of people that are allowed per visiting place considered in the model.

Besides the capacity the touristic places can hold, the model also requires information about the demand on the ports, because these are the places from where the vessels sail, hence, from where they pick up the passengers. The demand was calculated per port using the information of the sailings of the vessels provided by the Undersecretariat of Ports. To get a more realistic number the information taken was from the sailings from December 2019, because that month had the most information without missing values. The demand then was calculated by adding the number of sails per vessel encountered multiplied by their own capacities. The obtained demand per port is shown in Appendix 14.

Once all this information was gathered, it was possible to use it in the model developed. Once again, the software used was AMPL with the solver Gurobi. The software took more than five hours to return a solution due to the high amount of information considered and all the constraints established. The optimal solution shows the total distance plus the route that each vessel should cover. The total distance obtained was 12742.3 km. The routes obtained are shown in Appendix 6. However, due to the limited space, the routes are listed showing the number of the place visited that was stated on Appendix 5. To clarify this, the first vessels' route is shown and mentioned below, considering that each vessel visits two places per day (see Table 5). This example is as well shown in the map on Appendix 15.

Table 5. Vessel Angelito I´s itinerary

Day (Time)	**From**	**To**
Monday (AM)	Puerto Seymour	Baltra
Monday (PM)	Baltra	Mosquera
Tuesday (AM)	Mosquera	Seymour Norte
Tuesday (PM)	Seymour Norte	Daphne Mayor
Wednesday (AM)	Daphne Mayor	Bartolome
Wednesday (PM)	Bartolome	Bahía Sullivan
Thursday (AM)	Bahía Sullivan	Bahía Post Office
Thursday (PM)	Bahía Post Office	La Lobería
Friday (AM)	La Lobería	Champion
Friday (PM)	Champion	El Barranco
Saturday (AM)	El Barranco	Rocas Gordon
Saturday (PM)	Rocas Gordon	Punta Carrión
Sunday (AM)	Punta Carrión	Playa Las Bachas
Sunday (PM)	Playa Las Bachas	Puerto Seymour

With the results obtained it is now possible to compare the actual distance travelled with the distance travelled with the optimal routes. In order to determine the distance between two points the Euclidean distance was used. Then with the patents of operation of the 32 vessels considered for the model it was possible to calculate the distance travelled by each vessel according to the itinerary that they cover. Once this was done, the total distanced travelled, adding the distance travelled by each vessel, was approximately 21937 km. In comparison with the distance travelled with the optimal solution of 12742.3 km it can be said that there is a saving of around 9194.7 km. However, the important thing is to show the amount of money that this represents. For that, the amount of fuel consumed by the vessels was determined through an approximation. For this, the most frequent model of boat was used, the Azimut PB70. Which performance is 5 gal/km (Yachtall, 2018), also the price of the gasoline the ships use is USD 2.30/gal (GPP, 2019). With that information, it is possible to calculate the amount of money saved with the new routes. Reducing around USD 105739.05 per week for the whole fleet of vessels considered.

6.2.1. Tourist maritime transportation model – Sensitivity Analysis

The results obtained considered that all the vessels travel at their full capacity, which is not always the real situation. As stated in the problem this kind of transportation is prone to changes on the demand in the different seasons. Due to that, it seemed necessary to compare different situations changing the demand of people in each of the main ports of the different Islands. Hence, for this sensitivity analysis two variations of the demand from the one used on the main model are stated next.

For the first variation, a demand of 80% was used. This data is shown in Appendix 16. All the other input data stayed the same. The model was run once again in AMPL using the solver Gurobi and the results obtained are a total traveling distance of 7283.6 km and the routes established on Appendix 17.

The second variation of the model was using a demand of 50% from the main demand used. For this case the demand is shown in Appendix 18. Then the model was run with the same conditions as the previous one. The results obtained include the set of routes depicted in Appendix 19 and a total distance travelled of 19648.7 km.

The distance travelled differs from one model to another, this can be due to the fact that as the demand is different the vessels can take other routes satisfying all the requirements that are implied. However, these results are the ones that the vessels should follow depending on the demand expected on the different seasons of the year in order to satisfy the customer needs and optimize the human movement involved in this type of transportation.

Even though the model established on section 5.2 delivers a preliminary solution it does not explain the complete scenario of the tourist transportation system. This has to do with the limitations that appeared during the project, including the difficulties of gathering the latest data regarding the tourist transportation, which in turn made it impossible to know the time restrictions for the vessels operating in the Islands.

However, for a complete understanding, in case all the necessary information is known, certain constraints can be added to the mentioned model in order to take into consideration the Time-Windows conditions to explain a wider range of reality in a future research. As proposed by Cantu-Funes, et. Al (2017) to do this an implementation of the MDPVRPTW (Multi-Depot Vehicle Routing Problem with Time Windows) must be considered , a new set should be considered (P) regarding the planning horizon that each vessel should cover, new parameters that establish the time window and duration of a working day and a new variable that states the starting time of the trip. In addition, constraint (14) must be removed. In order to generate this new model, the following mathematical formulation can be added:

$\boldsymbol{Sets}$:

$P\ set\ of\ planning\ horizon$

$\boldsymbol{Parameters}$:

a_j: $initial\ time\ regarding\ the\ time\ window$

b_j: $ending\ time\ regarding\ the\ time\ window$

T: $duration\ of\ a\ working\ day$

Variables:

$$s_{kl}^{p}: starting\ time\ of\ trip\ l\ of\ vessel\ k\ in\ period\ p$$

Constraints:

$$s_{kl}^{p} + \sum_{(i,j)\in A} x_{ijkl}^{p}(t_{ij} + t_{ji}) \leq s_{kl+1}^{p}, \quad \forall p \in P, \forall k \in K, \forall l \in L \setminus \{l_{max}\} \quad (15)$$

$$s_{kl}^{p} + \sum_{(i,j)\in A} t_{ij} x_{ijkl}^{p} \geq \sum_{(i,j)\in A} a_j x_{ijkl}^{p}, \quad \forall p \in P, \forall k \in K, \forall l \in L \quad (16)$$

$$s_{kl}^{p} + \sum_{(i,j)\in A} t_{ij} x_{ijkl}^{p} \leq \sum_{(i,j)\in A} b_j x_{ijkl}^{p}, \quad \forall p \in P, \forall k \in K, \forall l \in L \quad (17)$$

$$s_{kl}^{p} + \sum_{(i,j)\in A} x_{ijkl}^{p}(t_{ij} + t_{ji}) \leq T, \quad \forall p \in P, \forall k \in K, \forall l \in L. \quad (18)$$

Constraint (15) assures a time consistency between the trips consecutively performed by a vessel, which means that a vessel cannot start a new trip before finishing the previous one. Constraint (5) and (6) guarantees that the upper- and lower-time bounds are respected. Constraint (18) impose that the total time a vessel is active does not exceed the duration of a working day.

7. Conclusions

The results of this research rely on the generation of route planning for the two different types of transport in the Galapagos Islands, public and tourist. The main purpose of doing this was to establish a basis for a bigger and more exhaustive research, gathering more information and overcoming the limitations that appeared on this research, therefore covering more areas of interest.

Through this study better understanding of the situation of both types of transport was obtained, making it possible to give preliminary models that can show an optimization of the inter-island routes taking into consideration all the existing constraints. One of them being the demand on the ports, either in the public sector as in the tourist one. Also, the capacity of the vessels that are designated to perform each of the routes, as well as the carrying capacity of the visiting places.

Regarding the public sector, the optimization models showed, first of all that with 18 vessels it is possible to satisfy the demand on the ports, hence, reducing the operating costs from $15 500 to $9 000 per day. Second of all, with the second model used for the public sector it was possible to show new routes that the vessels should cover that are more optimal than the ones established. However, these new routes are just a suggestion, in order to change the situation, there has to be an approval of all the organizations involved, because there could be restrictions in the Islands that were not considered.

For the tourist sector, the preliminary model showed on this work gives an example of the optimization of the itineraries that the vessels in charge of this sector should cover. With the new routes the transport costs reduced around USD 105 739.05 per week for the whole fleet of vessels considered. This means that it is possible to establish new routes for the vessels that will reduce the amount of fuel consumption, hence reducing the amount of gas emissions. However, it is necessary to emphasize that this model is indeed preliminary, but it gives the opportunity to understand the changes that should be considered, and it is a basis for a next study of this situation.

Even though the study showed preliminary results regarding the Islands maritime transport, there were some limitations that emerged along the research that made it difficult to gather the most updated data. Due to that, it is suggested to consider this study as a first basis for future research in this field. Along the limitations that appeared along the way is the fact that most of the information needed is not available for public access and the required procedures that have to be followed take great amount of time.

8. References

Alarcón, F. (2015). Reglamento a la Actividad Marítima. Decreto No.168. Retrieved from: https://www.obraspublicas.gob.ec/wp-content/uploads/downloads/2015/04/LOTAIP2015_REGLAMENTO-A-LA-ACTIVIDAD-MARITIMA.pdf

Alexandre, J., Fregnani, T. G., De Mattos, B. S., & Hernandes, J. A. (2019). An innovative approach for integrated airline network and aircraft family optimization. *Chinese Journal of Aeronautics*. https://doi.org/10.1016/j.cja.2019.10.004

Amador, E. et. al. (1996). Determinación de la Capacidad de Carga Turística en los Sitios de Visita del Parque Nacional Galápagos. Servicio Parque Nacional Galápagos

Andersson, P., & Ivehammar, P. (2017). Dynamic route planning in the Baltic Sea Region - A cost-benefit analysis based on AIS data oa. *Maritime Economics and Logistics*, *19*(4), 631–649. https://doi.org/10.1057/mel.2016.18

Cantu-Funes et al (2017). Multi-Depot Periodic Vessel Routing Problem with Due Dates and Time Windows. Journal of the Operational Research Society. doi:10.1057/s41274-017-0206-7.

Charles Darwin Foundation Galápagos (2017). Natural History Collections. *CDF*. Retrieved 12 de February 2020 from: https://www.darwinfoundation.org/en/about/cdrs/collections

Chen, G., Wu, X., Li, J., & Guo, H. (2020). Green Vessel Routing and Scheduling Optimization of Ship Steel Distribution Center Based on Improved Intelligent Water Drop Algorithms. Mathematical Problems in Engineering, 2020, 1–13. https://doi.org/10.1155/2020/9839634

Coene, S., Arnout A. & Spieksma, F.C.R. (October, 29, 2008). The Periodic Vessel Routing Problem: A Case Study. Katholieke Universiteit Leuven, Operations Research Group, Naamsestraat 69, B-3000. Leuven, Belgium.

De, A., Kumar, S. K., Gunasekaran, A., & Tiwari, M. K. (2017). Sustainable maritime inventory routing problem with time window constraints. Engineering Applications of Artificial Intelligence, 61(February), 77–95. https://doi.org/10.1016/j.engappai.2017.02.012

Ecuadorian National Transit Agency. (2019). Tarifario de Rutas Interprovinciales –

Resolución Nro.077-DIR-2019-ANT.

El-Sherbeny, N. A. (2010). Vessel routing with time windows: An overview of exact, heuristic and metaheuristic methods. *Journal of King Saud University - Science, 22*(3), 123–131. https://doi.org/10.1016/j.jksus.2010.03.002

Galapagos National Park Directorate (2019). Informe anual de visitantes a las áreas protegidas de Galápagos del año 2019. Galápagos - Ecuador. www.galapagos.gob.ec

Galapagos National Park Directorate (2019). Administración de la operación turística. Retrieved from http://www.galapagos.gob.ec/administracion-de-la-operacion-turistica/

Galapagos National Park Directorate (4 de octubre, 2016). Participación local, cupos y patentes de operación turística. Retrieved from: http://www.carlospi.com/galapagospark/turismo_participacion_cupos_patentes.html

Galapagos National Park. (2020). Reporte Patentes Feb 2020.

Galapagos National Park. (2015). Geografía. Retrieved from http://areasprotegidas.ambiente.gob.ec/es/areas-protegidas/parque-nacional-galápagos

Galapagos Tourism Observatory. (2019). Estadísticas de Turismo de Galápagos 2018.

Global Petrol Prices (GPP) (2019). Ecuador Precios de la Gasolina. Retrieved 18 April 2020 from: https://es.globalpetrolprices.com/Ecuador/gasoline_prices/

Go Galapagos. (2018). Retrieved from: https://www.gogalapagos.com

Hatziioannidu, F., & Polydoropoulou, A. (2017). Passenger Demand and Patterns of Tourists' Mobility in the Aegean Archipelago with Combined Use of Big Datasets from Mobile Phones and Statistical Data from Ports and Airports. *Transportation Research Procedia*, *25*, 2309–2329. https://doi.org/10.1016/j.trpro.2017.05.442

Hillier, F.S. & Lieberman, G.J. (2015) Introduction to Operations Research, 7th Editon. New York: McGraw-Hill.

Hu, Z. (2018). Model and Algorithm for the Large Material Distribution Problem in Maritime Transportation. *Journal of Coastal Research*, 82, 294–306. https://doi.org/10.2112/si82-042.1

INEC. (2015). Principales resultados Censo de Población y Vivienda Galápagos 2015. Retrieved from: https://www.ecuadorencifras.gob.ec/documentos/web-inec/Poblacion_y_Demografia/CPV_Galapagos_2015/Presentacion_CPVG15.pdf

Juliandri, D., Mawengkang, H. & Bu'ulolo, F. (2018). Discrete Optimization Model for Vessel Routing Problem with Scheduling Side Cosntraints. OP Conf. Series: Materials Science and Engineering. Retrieved from: https://iopscience.iop.org/article/10.1088/1757-899X/300/1/012024/pdf

Kim, K. Il, & Lee, K. M. (2019). Adaptive information visualization for maritime traffic stream sensor data with parallel context acquisition and machine learning. Sensors (Switzerland), 19(23). https://doi.org/10.3390/s19235273

Kır, S., Yazgan, H. R., & Tüncel, E. (2017). A novel heuristic algorithm for capacitated vessel routing problem. Journal of Industrial Engineering International, 13(3), 323–330. https://doi.org/10.1007/s40092-017-0187-9

Latarche, M. (October 17, 2017). NOx emissions from ships. ShipsInsight. Retrieved from: https://shipinsight.com/articles/nox-emissions-from-ships

Maclin, E. (2018) Carrying Capacity in an Ecosystem. Sciencing. Retrieved 16 de April 2020 from: https://sciencing.com/carrying-capacity-ecosystem-5201.html

Mancini, S., & Stecca, G. (2018). A large neighborhood search based matheuristic for the tourist cruises itinerary planning. Computers and Industrial Engineering, 122, 140–148. https://doi.org/10.1016/j.cie.2018.05.045

Maragoudakis, M. (2019). Data analysis, simulation and visualization for environmentally safe maritime data. Algorithms, 12(1). https://doi.org/10.3390/a12010027

Minato, N., & Morimoto, R. (2011). Sustainable airline strategy using portfolio theory: A case study of remote islands in Japan. Journal of Air Transport Management, 17(3), 195–198. https://doi.org/10.1016/j.jairtraman.2010.12.009

Puerto Ayora Port Capitaincy. (2019). Solicitud de Zarpe y Rol de Tripulación.

Ramos T. et. al (2019). Multi-depot vessel routing problem: a comparative study of alternative formulations. International Journal Of Logistics: Research And Applications. https://doi.org/10.1080/13675567.2019.1630374

Sherali H., Bish E. and Zhu X. (2005). Airline fleet assignment concepts, models and algorithms. European Journal of Operation Research, 172, 1-30

Betancourt C. and Salvador J. (2020). Transgal cooperative operational functioning. Personal. Santa Cruz, Galapagos Archipelago.

Singh, S., Dubey, G. C. and Shrivastava, R. (2012). A Comparative Analysis of Assignment Problem. IOSR Journal of Engineering.

Surekha, P. & Sumathi,S. (August, 2011). Solution To Multi-Depot Vessel Routing

Problem Using Genetic Algorithms. World Applied Programming, Vol (1), No (3), August 2011.

Undersecretariat of Ports. (2019). Naves del servicio público relacionadas con el transporte marítimo de pasaje entre los puertos poblados de la Provincia de Galápagos (periodo 2019).

Undersecretariat of Ports. (2019). Normativa para la prestación del servicio público del transporte marítimo de pasajeros entre puertos poblados de la Provincia de Galápagos.

Undersecretariat of Ports. (2019). Normativa para la prestación del Servicio público del transporte marítimo de pasajeros entre puertos poblados de la Provincia de Galápagos.

Yachtall (2018). Azimut PB70 Information. Yachtall. Retrieved the 18 of April 2020 from: https://www.yachtall.com/es/barco/azimut-62-fly-329040

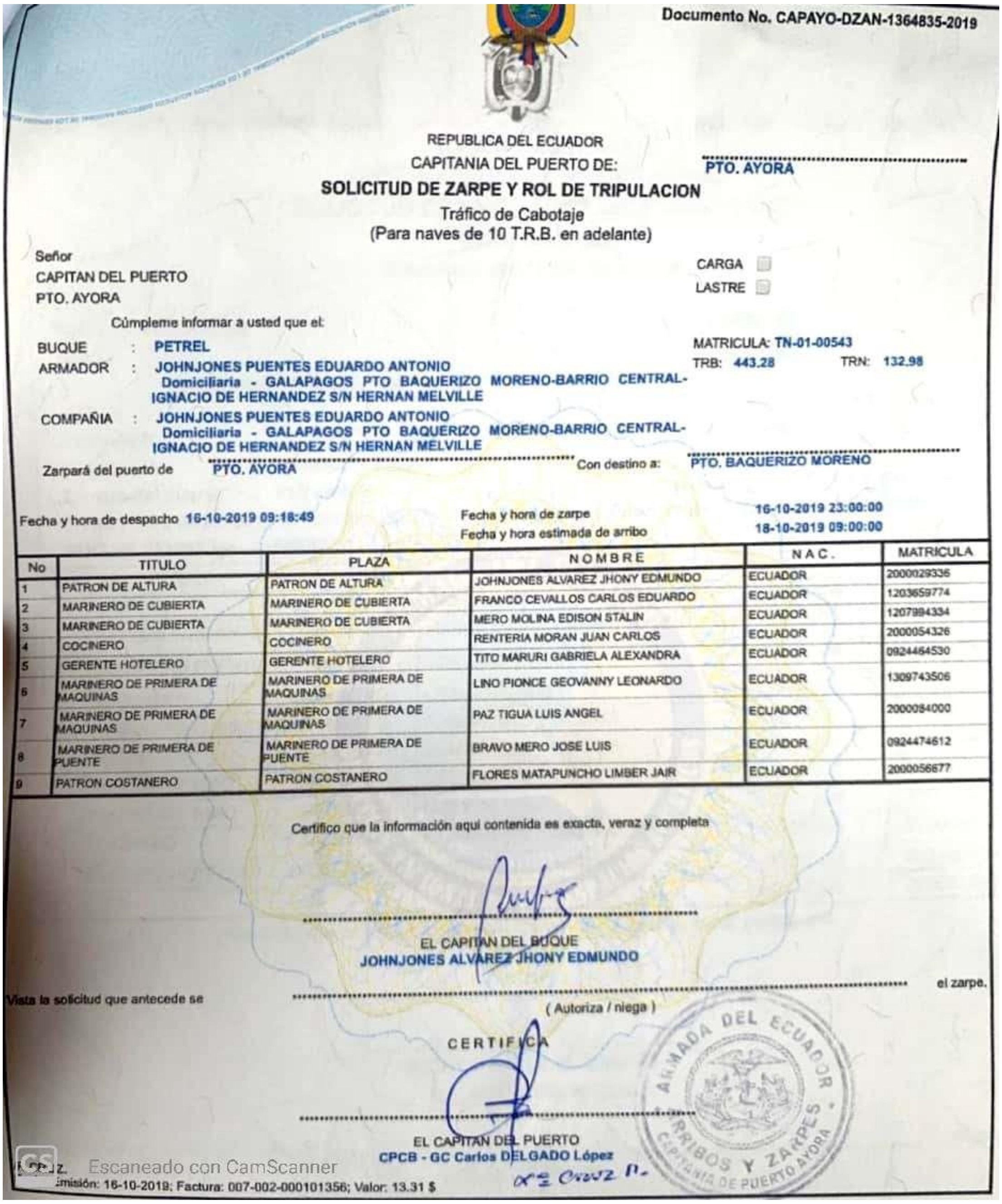
Li Y. and Tan N. (2013) Study on Fleet Assignment Problem and Algorithm. Aeronautical Engineering College, Civil Aviation University of China. Mathematical Problems in Engineering Volume 2013, Article ID 581586. http://dx.doi.org/10.1155/2013/581586

Zhang, J., Zhao, Y., Xue, W., & Li, J. (2015). Vessel routing problem with fuel consumption and carbon emission. International Journal of Production Economics, 170, 234–242. https://doi.org/10.1016/j.ijpe.2015.09.031

Zito, P., Salvo, G., & La Franca, L. (2011). Modelling airlines competition on fares and frequencies of service by bi-level optimization. Procedia - Social and Behavioral Sciences, 20, 1080–1089. From: https://doi.org/10.1016/j.sbspro.2011.08.117

9. Appendices

APPENDIX 1. DEPARTURE OF THE VESSEL (ZARPE) EXAMPLE



Documento No. CAPAYO-DZAN-1364835-2019

REPUBLICA DEL ECUADOR
CAPITANIA DEL PUERTO DE: PTO. AYORA
SOLICITUD DE ZARPE Y ROL DE TRIPULACION
Tráfico de Cabotaje
(Para naves de 10 T.R.B. en adelante)

Señor
CAPITAN DEL PUERTO
PTO. AYORA

CARGA
LASTRE

Cúmpleme informar a usted que el:

BUQUE : PETREL
ARMADOR : JOHNJONES PUENTES EDUARDO ANTONIO
Domiciliaria - GALAPAGOS PTO BAQUERIZO MORENO-BARRIO CENTRAL-IGNACIO DE HERNANDEZ S/N HERNAN MELVILLE
COMPAÑIA : JOHNJONES PUENTES EDUARDO ANTONIO
Domiciliaria - GALAPAGOS PTO BAQUERIZO MORENO-BARRIO CENTRAL-IGNACIO DE HERNANDEZ S/N HERNAN MELVILLE

MATRICULA: TN-01-00543
TRB: 443.28 TRN: 132.98

Zarpará del puerto de PTO. AYORA Con destino a: PTO. BAQUERIZO MORENO

Fecha y hora de despacho 16-10-2019 09:18:49
Fecha y hora de zarpe 16-10-2019 23:00:00
Fecha y hora estimada de arribo 18-10-2019 09:00:00

No	TITULO	PLAZA	NOMBRE	NAC.	MATRICULA
1	PATRON DE ALTURA	PATRON DE ALTURA	JOHNJONES ALVAREZ JHONY EDMUNDO	ECUADOR	2000029336
2	MARINERO DE CUBIERTA	MARINERO DE CUBIERTA	FRANCO CEVALLOS CARLOS EDUARDO	ECUADOR	1203659774
3	MARINERO DE CUBIERTA	MARINERO DE CUBIERTA	MERO MOLINA EDISON STALIN	ECUADOR	1207994334
4	COCINERO	COCINERO	RENTERIA MORAN JUAN CARLOS	ECUADOR	2000054326
5	GERENTE HOTELERO	GERENTE HOTELERO	TITO MARURI GABRIELA ALEXANDRA	ECUADOR	0924464530
6	MARINERO DE PRIMERA DE MAQUINAS	MARINERO DE PRIMERA DE MAQUINAS	LINO PIONCE GEOVANNY LEONARDO	ECUADOR	1309743506
7	MARINERO DE PRIMERA DE MAQUINAS	MARINERO DE PRIMERA DE MAQUINAS	PAZ TIGUA LUIS ANGEL	ECUADOR	2000084000
8	MARINERO DE PRIMERA DE PUENTE	MARINERO DE PRIMERA DE PUENTE	BRAVO MERO JOSE LUIS	ECUADOR	0924474612
9	PATRON COSTANERO	PATRON COSTANERO	FLORES MATAPUNCHO LIMBER JAIR	ECUADOR	2000056677

Certifico que la información aquí contenida es exacta, veraz y completa

EL CAPITAN DEL BUQUE
JOHNJONES ALVAREZ JHONY EDMUNDO

Vista la solicitud que antecede se .... el zarpe.
(Autoriza / niega)

CERTIFICA

EL CAPITAN DEL PUERTO
CPCB - GC Carlos DELGADO López

ARMADA DEL ECUADOR
ARRIBOS Y ZARPES
CAPITANIA DE PUERTO AYORA

Escaneado con CamScanner
Emisión: 16-10-2019; Factura: 007-002-000101356; Valor: 13.31 $

Source: (Puerto Ayora Port Capitaincy, 2019)

APPENDIX 2. OPERATION PATENT EXAMPLE

-83-

Ministerio del Ambiente

DIRECCIÓN DEL PARQUE NACIONAL GALÁPAGOS
Dirección de Uso Público

PATENTE DE OPERACIÓN TURÍSTICA
DOCUMENTO INTRANSFERIBLE NO NEGOCIABLE

2017 - 2018

COPIA

Nombre / Razón Social del Operador: **ADOLFO AURELIO FLOR GIL**

Número de Inscripción en el Registro Forestal del Ministerio del Ambiente: **ND**

Número de Inscripción en el Registro Forestal del Parque Nacional Galápagos: **150**

Nombre de la Embarcación: **ESTRELLA DE MAR ****

Número de la Matrícula de la Embarcación: **TN-01-01036**

Capacidad Autorizada de Pasajeros: **16 - Dieciséis**

Categoría de Operación: **Crucero navegable A**

Área de Operación: **Áreas Protegidas de Galápagos**

Valor de los Derechos por Obtención de Patente: **$ 4.000,00**

Número de Factura de Pago de Derechos: **1223**

Expedido en: **Puerto Ayora**
Al: **27 de Abril de 2017**

Periodo de Vigencia:
Desde: **01/MAY/2017** Hasta: **31/MAR/2018**

Observaciones:
Las actividades permitidas se podrán realizar únicamente en los sitios aquí señalados. El número máximo de kayaks o tablas a remo es de 8 más 1 para uso del Guía Naturalista; conforme a Resoluciones 56/Ago-9-2010 y 24/Abr-14-2016.

Lcda. Verónica Santamaría Delgado
DIRECTORA DE USO PUBLICO
Parque Nacional Galápagos

Itinerario	Act.Permitidas
Lunes 1 AM() - Centro de interpretación	CA
Lunes 1 PM(15H30-18H00) - Isla Lobos	CA,PR,SN
Martes 1 AM() - Islote Punta Pitt	SN
Martes 1 AM() - Punta Pitt	CA,KY,PR,SN
Martes 1 PM() - Cerro Brujo	CA,KY,PR,SN
Martes 1 PM(16H00-18H00) - León Dormido	SN
Miércoles 1 AM() - Islote Osborn	SN
Miércoles 1 AM() - Islote Gardner (Española)	PR,SN
Miércoles 1 AM() - Bahía Gardner	CA,KY,SN
Miércoles 1 PM() - Punta Suarez	CA
Jueves 1 AM() - Mirador de la Baronesa	CA,KY,PR
Jueves 1 AM() - Bahía Post Office	CA,SN
Jueves 1 PM() - Corona del Diablo	SN
Jueves 1 PM() - Punta Cormorant	CA,PR,SN
Viernes 1 AM(06H00-10H00) - Seymour Norte	CA,PR,SN
Viernes 1 PM(15H30-18H00) - Bartolomé	CA,PR,SN
Sábado 1 AM() - Bahía Darwin	CA,KY,PR,SN
Sábado 1 PM() - El Barranco	CA,KY,PR,SN
Domingo 1 AM(06H00-10H00) - Plaza Sur	CA
Domingo 1 PM(15H30-18H00) - Santa Fe	CA,KY,PR,SN
Lunes 2 AM() - El Chato	CA
Lunes 2 AM() - Los Gemelos (G)	CA
Lunes 2 PM() - C.C. Fausto Llerena	CA
Martes 2 AM(06H00-10H00) - Sombrero Chino	CA,KY,PR,SN
Martes 2 PM() - Rábida	CA,KY,PR,SN
Miércoles 2 AM() - Caleta Bucanero	KY,PR,SN
Miércoles 2 AM() - Playa Espumilla	CA,KY,PR,SN
Miércoles 2 PM() - Puerto Egas	CA,SN
Jueves 2 AM() - Punta Espinoza	CA,SN
Jueves 2 PM() - Bahía Urbina	CA,SN
Viernes 2 AM() - Bahía Elizabeth	PR
Viernes 2 PM() - Punta Moreno	CA,PR,SN
Sábado 2 AM(06H00-08H30) - Tintoreras	CA,KY,PR,SN
Sábado 2 AM(10H00-12H00) - V.Chico/Sierra Negra	CA
Sábado 2 PM() - Muro de las Lagrimas	CA
Sábado 2 PM() - C.C. Arnaldo Tupiza	CA
Sábado 2 PM() - Humedales	CA
Domingo 2 AM() - C.C. Fausto Llerena	CA
Domingo 2 PM() - Bahía Tortuga	CA,SN

Nomenclatura:
SC: Buceo Scuba; SN: Snorkel; PR: Panga Ride; CA: Caminata; BN: Buceo Nocturno; KY: Kayak; CD: Check dive

www.galapagos.gob.ec

Source: (Galapagos National Park, 2020)

APPENDIX 3. OPERATION PATENT LIST

MINISTERIO DEL AMBIENTE   Parque Nacional GALÁPAGOS Ecuador

EL GOBIERNO DE TODOS

PATENTES DE OPERACIÓN TURÍSTICA

Reporte de Patentes de Operación Turística vigentes desde 01-04-2019 hasta 31-03-2020

No.	EMBARCACIÓN	RAZÓN SOCIAL	MATRICULA	TRN	TRB	Nro. PASAJEROS	PUERTO OPERACIÓN	MODALIDAD OPERACIÓN	RF PNG	RF MAE	CONTRATO	ARMADOR
1	7 MARES I	ROBERTO LENIN NARANJO MARTINEZ,	TN-01-00526	49.18	49.18	12	PUERTO BAQUERIZO MORENO	TOUR DIARIO DE BUCEO	149	0	NINGUNO	ROBERTO LENIN NARANJO MARTINEZ,ROBERTO LENIN NARANJO MARTINEZ
2	ADRIANA *	DANIEL HORACIO ANDRADE BALLESTEROS	TN-00-00919	28.2	28.2	16	PUERTO AYORA	TOUR DIARIO	179	0	C. MERCANTIL O LEASING	FAUSTO ADRIANO RODRIGUEZ RODRIGUEZ
3	AIDA MARIA	ALICIA MARGOT AYALA CHACA, CLEMENCIA AYALA CHACA, GLORIA IRENE AYALA CHACA, LUIS AYALA CHACA, AIDA MARIA AYALA CHACA	TN-01-00080	101.88	101.88	16	PUERTO AYORA	TOUR DE CRUCERO NAVEGABLE	16	17	NINGUNO	AIDA MARIA AYALA CHACA,ALICIA MARGOT AYALA CHACA,CLEMENCIA AYALA CHACA,GLORIA IRENE AYALA CHACA,LUIS AYALA CHACA
4	ALBATROS	GALAEX S.A.	TN-01-00154	135.93	135.93	16	PUERTO AYORA	TOUR DIARIO	24	25	NINGUNO	GALAEX S.A.
5	ALTAMAR	AYALA EGAS VERÓNICA CECILIA, HERRERA VILLACIS FREDDY ENRIQUE	TN-01-00288	49.19	49.19	16	PUERTO AYORA	TOUR DIARIO	67	74	NINGUNO	VERÓNICA CECILIA AYALA EGAS
6	ALYA	JANNET DE LAS MERCEDES GUTIERREZ GUERRERO,	TN-01-00401	369.1	369.1	16	PUERTO BAQUERIZO MORENO	TOUR DE CRUCERO NAVEGABLE	21	22	NINGUNO	JANNET DE LAS MERCEDES GUTIERREZ GUERRERO
7	ANA BELEN	VICTOR SANTIAGO LUCIO VACA, ANA BELÉN LUCIO CABRERA, MARÍA JOSÉ LUCIO CABRERA, GRACIELA ENRIQUETA GONZALES BAJAÑA	TN-01-00299	8.1	8.1	16	PUERTO AYORA	TOUR DE BAHÍA	170	0	NINGUNO	VICTOR SANTIAGO LUCIO VACA
8	ANAHI	VIAJES UNIGALAPAGOS S.A.	TN-01-00221	221.23	221.23	16	PUERTO AYORA	TOUR DE CRUCERO NAVEGABLE	103	118	NINGUNO	VIAJES UNIGALAPAGOS S.A
9	ANDALE	ÁNGEL TRISTÁN MEJÍA POVEDA,	TN-01-00949	12.9	12.9	10	PUERTO BAQUERIZO MORENO	TOUR DE PESCA VIVENCIAL	193	0	NINGUNO	ÁNGEL TRISTÁN MEJÍA POVEDA
10	ANDRY	JOHN ALEX RAMÍREZ ROGEL	TN-01-00525	6.99	6.99	10	PUERTO BAQUERIZO MORENO	TOUR DE PESCA VIVENCIAL	192	0	NINGUNO	JOHN ALEX RAMÍREZ ROGEL
11	ANGELES THAIZ	ZARABIA CARLOS ALBERTO	TN-01-00287	14.15	14.15	10	PUERTO AYORA	TOUR DE PESCA VIVENCIAL	215	0	C. MERCANTIL O LEASING	MIGUEL ÁNGEL GARCÍA ZAPATA

1 / 16

Santa Cruz, Pto. Ayora: (PBX): (593 5) 2 526189/190 • info@galapagos.gob.ec • Código Postal: 200102 • San Cristóbal, Pto. Baquerizo Moreno: Tel./Fax.: (593 5) 2 520138/497/476 • Código Postal: 200101 • Isabela, Pto. Villamil: Tel: (593 5) 2 529178/268 • Código Postal: 200103 Floreana, Pto. Velasco Ibarra: Tel: (593 5) 2 535 009 • RUC: 2060002010001

Source: (Galapagos National Park, 2020)

APPENDIX 4. TOURIST VESSELS AND THEIR CAPACITIES.

Vessel Name	Passenger Capacity
Aida Maria	16
Albatros	16
Amazonia	16
Anahi	16
Angelito I	16
Archipell II	16
Coral II	20
Daphne	16
Darwin	16
Deep Blue	16
Eden	16
Evolution	32
Flamingo I	16
Fragata	16
Galapagos Adventure	16
Galapagos Adventure II	16
Galaxy	16
Golondrina I	16
Gran Monserrat	16
Integrity	16
Jesus del Gran Poder	16
Mary Anne	16
Millenium	16
Monserrat	20
National Geographic Islander	48
Reina Silvia	16
Samba	16
Sea Finch	16
The Beagle	16
Tip Top IV	16
Xavier III	16
Yolita II	16

APPENDIX 5. TOURISTIC PLACES AND CARRYING CAPACITY

Number	Place Visited	Carrying Capacity
1	Bahia Darwin	85
2	Bahia Elizabeth	96
3	Bahia Post Office	204
4	Bahia Sullivan	323
5	Baltra	96
6	Bartolome	238
7	Champion	96
8	Daphne Mayor	68
9	El Arco	96
10	El Barranco	64
11	Isla Gardner	112
12	Isla Lobos	119
13	Isla Osborn	96
14	Isla Wolf	96
15	La Loberia	32
16	Las Tintoreras	221
17	Leon Dormido	80
18	Mosquera	255
19	Playa las Bachas	816
20	Playa Ochoa	391
21	Plaza Sur	187
22	Puerto Egas	476
23	Punta Carrion	112
24	Punta Espinoza	221
25	Punta Mangle	96
26	Punta Moreno	102
27	Punta Pitt	68
28	Punta Suarez	170
29	Punta Vicente Roca	80
30	Rabida	187
31	Roca Cousins	80
32	Rocas Gordon	80
33	Santa Fe	748
34	Seymour Norte	357

APPENDIX 6. MDPVRP MODEL RESULTS.

Vessel Name	Route
Aida Maria	P. Seymour-5-18-34-30-6-31-4-8-19-23-21-32-10-P. Ayora
Albatros	P. Seymour-8-6-4-31-22-21-32-23-5-18-34-12-20-P.Baquerizo Moreno
Amazonia	P. Seymour-18-34-30-31-4-6-8-19-5-23-21-32-10-P. Ayora
Anahi	P.Baquerizo Moreno-17-12-28-13-20-11-3-15-7-10-32-21-23-P. Seymour
Angelito I	P. Seymour-5-18-34-8-6-4-3-15-7-10-32-23-19-P. Seymour
Archipell II	P. Ayora-21-32-10-25-13-27-16-24-15-22-30-34-18-P. Seymour
Coral II	P.Baquerizo Moreno-12-20-33-32-21-19-8-6-31-4-30-34-18-P. Seymour
Daphne	P. Ayora-10-32-21-23-19-5-18-34-30-31-4-6-8-P. Seymour
Darwin	P.Baquerizo Moreno-20-12-17-33-21-32-23-19-8-6-4-30-34-P. Seymour
Deep Blue	P. Seymour-18-8-19-23-21-33-28-31-6-4-22-30-34-P. Seymour
Eden	P.Baquerizo Moreno-12-17-20-33-32-23-5-9-22-31-30-34-18-P. Seymour
Evolution	P. Ayora-21-32-23-19-8-6-4-31-30-34-20-17-12-P.Baquerizo Moreno
Flamingo I	P. Villamil-16-30-31-6-4-8-18-34-32-21-23-19-5-P. Seymour
Fragata	P.Baquerizo Moreno-20-12-33-21-32-23-19-8-6-4-30-34-18-P. Seymour
Galapagos Adventure	P.Baquerizo Moreno-12-17-20-33-21-32-5-34-30-31-6-8-18-P. Seymour
Galapagos Adventure II	P.Baquerizo Moreno-20-12-17-33-21-23-5-18-6-4-31-30-34-P. Seymour
Galaxy	P. Seymour-5-34-30-22-31-4-3-7-15-18-10-32-21-P. Seymour
Golondrina I	P. Seymour-8-4-31-6-34-7-14-1-17-30-22-5-18-P. Seymour
Gran Monserrat	P. Seymour-18-5-23-32-10-2-33-11-13-16-9-20-12-P.Baquerizo Moreno
Integrity	P.Baquerizo Moreno-12-20-17-33-21-23-5-8-6-4-30-34-18-P. Seymour
Jesus del Gran Poder	P. Seymour-5-23-32-21-1-24-2-4-6-30-34-8-18-P. Seymour
Mary Anne	P. Seymour-5-18-34-30-6-31-4-8-19-23-21-32-10-P. Ayora
Millenium	P. Villamil-16-3-7-14-30-20-13-27-21-32-23-5-18-P. Seymour
Monserrat	P.Baquerizo Moreno-20-12-17-33-10-32-21-23-19-8-34-5-18-P. Seymour
National Geographic Islander	P. Ayora-10-4-8-21-27-20-32-23-5-11-7-3-16-P. Villamil
Reina Silvia	P.Baquerizo Moreno-20-12-17-33-32-10-21-19-8-34-18-5-23-P. Seymour
Samba	P.Baquerizo Moreno-20-12-33-21-32-23-5-34-6-31-8-19-18-P. Seymour
Sea Finch	P. Villamil-16-3-15-7-10-32-21-23-19-8-34-18-5-P. Seymour
The Beagle	P. Seymour-18-34-30-31-4-6-19-33-10-32-21-23-5-P. Seymour
Tip Top IV	P. Seymour-5-18-34-8-6-31-4-3-7-15-25-32-10-P. Ayora
Xavier III	P. Villamil-16-2-25-24-26-11-22-18-34-8-19-23-5-P. Seymour
Yolita II	P. Villamil-16-2-26-25-33-20-31-4-6-30-34-18-5-P. Seymour

APPENDIX 7. DISTANCE BETWEEN PORTS (KM).

Departure Port \ Arrival Port	Puerto Ayora	Puerto Baquerizo Moreno	Puerto Velasco Ibarra	Puerto Villamil
Puerto Ayora	-	79.46	62.06	76.63
Puerto Baquerizo Moreno	79.46	-	105.67	150.58
Puerto Velasco Ibarra	62.06	105.67	-	63.91
Puerto Villamil	76.63	150.58	63.91	-

APPENDIX 8. VESSELS FOR PUBLIC TRANSPORT AND THEIR CAPACITIES

Number	Vessel Name	Passenger Capacity
1	ALBANY	22
2	ANDREA	24
3	ANDY	24
4	ANDY II	28
5	ANGY	29
6	ARRECIFE	33
7	BLUE FANTASY	24
8	BRITHANNY I	26
9	CALLY I	30
10	EL MANGLE	34
11	FRAGATA	22
12	GABI	22
13	GALAPAGOS OSPREY	35
14	GALAPAGOS PRIVILEGIO	32
15	GEMA	28
16	GLADEL	24
17	HIPPO CAMPUS	20
18	MI SOL	25
19	NEPTUNO	30
20	NEPTUNO I	23
21	NEW BRITHANY	26
22	NEW OCEAN	24
23	PODMAR	26
24	QUEEN ASTRID	20
25	SOLMAR	18
26	SPLENDOR I	30
27	SUNFISH	28
28	TROPICAL BIRD	28
29	TRUENO	22
30	UNDERTAKE I	24
31	WOLF	31

APPENDIX 9. CURRENT ROUTE COVERED BY EACH VESSEL

Number	Vessel Name	Route Covered
1	ALBANY	4
2	ANDREA	4
3	ANDY	2
4	ANDY II	2
5	ANGY	4
6	ARRECIFE	1
7	BLUE FANTASY	4
8	BRITHANNY I	4
9	CALLY I	4
10	EL MANGLE	4
11	FRAGATA	2
12	GABI	3
13	GALAPAGOS OSPREY	1
14	GALAPAGOS PRIVILEGIO	1
15	GEMA	2
16	GLADEL	3
17	HIPPO CAMPUS	3
18	MI SOL	4
19	NEPTUNO	4
20	NEPTUNO I	3
21	NEW BRITHANY	4
22	NEW OCEAN	4
23	PODMAR	2
24	QUEEN ASTRID	5
25	SOLMAR	4
26	SPLENDOR I	4
27	SUNFISH	1
28	TROPICAL BIRD	2
29	TRUENO	1
30	UNDERTAKE I	4
31	WOLF	1

APPENDIX 10. COST PER VESSEL PER ROUTE (USD).

Vessels \ Routes	1	2	3	4	5
ALBANY	-	-	-	500	-
ANDREA	-	-	-	500	-
ANDY	-	500	-	-	-
ANDY II	-	500	-	-	-
ANGY	-	-	-	500	-
ARRECIFE	500	-	-	-	-
BLUE FANTASY	-	-	-	500	-
BRITHANNY I	-	-	-	500	-
CALLY I	-	-	-	500	-
EL MANGLE	-	-	-	500	-
FRAGATA	-	500	-	-	-
GABI	-	-	500	-	-
GALAPAGOS OSPREY	500	-	-	-	-
GALAPAGOS PRIVILEGIO	500	-	-	-	-
GEMA	-	500	-	-	-
GLADEL	-	-	500	-	500
HIPPO CAMPUS	-	-	500	-	-
MI SOL	-	-	-	500	-
NEPTUNO	-	-	-	500	-
NEPTUNO I	-	-	500	-	-
NEW BRITHANY	-	-	-	500	-
NEW OCEAN	-	-	-	500	-
PODMAR	-	500	-	-	-
QUEEN ASTRID	-	-	-	-	500
SOLMAR	-	-	-	500	-
SPLENDOR I	-	-	-	500	-
SUNFISH	500	-	-	-	-
TROPICAL BIRD	-	500	-	-	-
TRUENO	500	-	-	-	-
UNDERTAKE I	-	-	-	500	-
WOLF	500	-	-	-	-

APPENDIX 11. PUBLIC TRANSPORT DEMAND IN NUMBER OF PASSENGERS PER PORT.

Port	Demand (number of people)
Puerto Ayora	164
Puerto Baquerizo Moreno	186
Puerto Velasco Ibarra	56
Puerto Villamil	278

APPENDIX 12. ROUTES DIVIDED BY PORT COVERED.

Port	Vessels
Puerto Ayora	1,2,3,4,5,7,8,9,10,11,15,18,19,21,22,24,25,26,28,30
Puerto Baquerizo Moreno	6,13,14,27,29,31
Puerto Villamil	12,16,17,20
Puerto Velasco Ibarra	23

APPENDIX 13. DISTANCE MATRIX BETWEEN THE PORTS AND VISITING PLACES. (THE PORTS ARE DIFFERENTIATED IN PARENTHESIS)

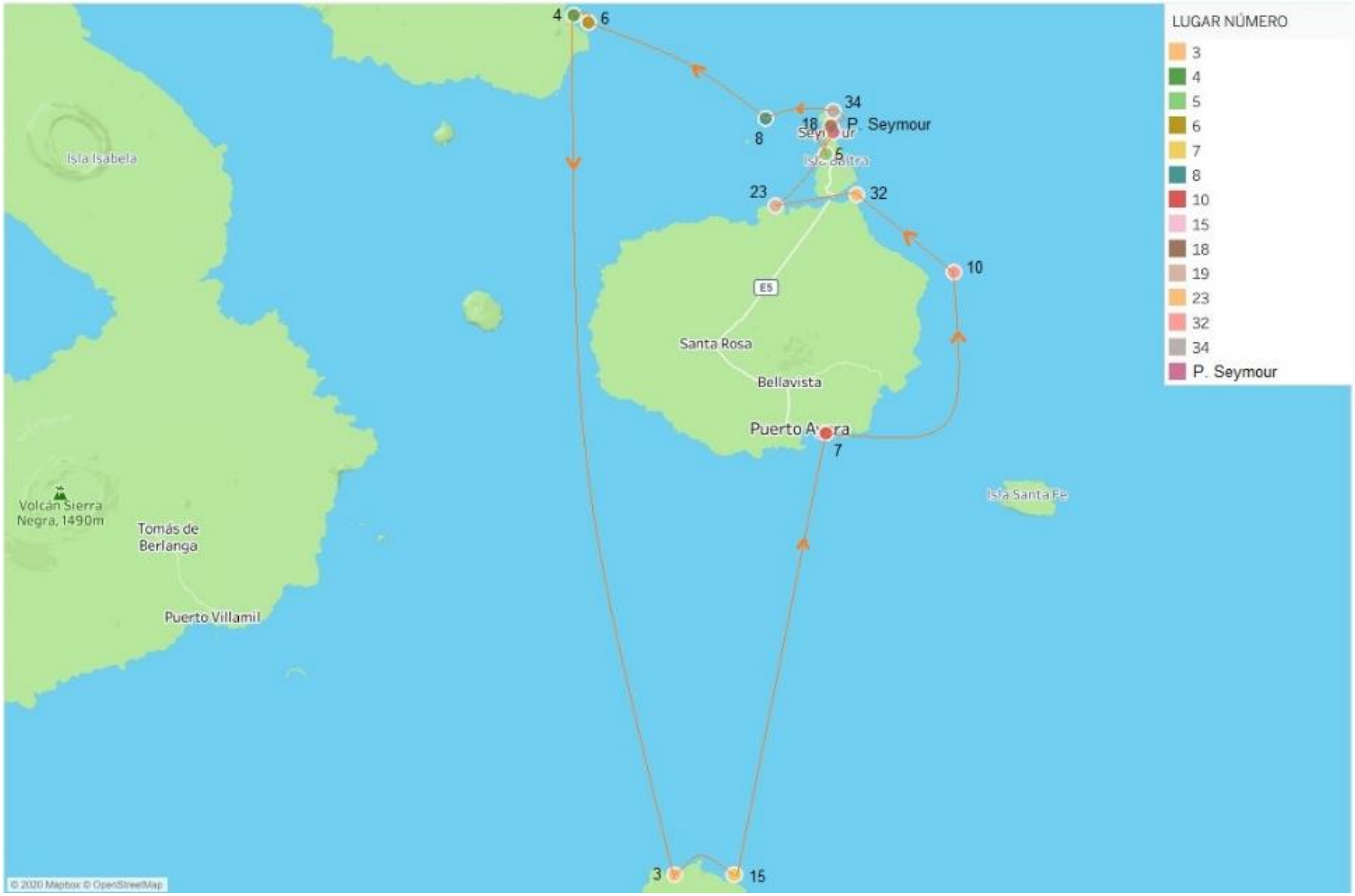
Vertex i \ Vertex j	Isabela (port)	Santa Cruz (port)	San Cristobal (port)	Seymour (port)	Baltra	Bartolome	Daphne Mayor	El Arco	Isla Gardner	Isla Osborn	Punta Suarez	Punta Espinoza	Punta Mangle	Bahia Post Office	Champion	La Loberia	Bahia Darwin	Bahia Elizabeth	Las Tintoreras
Isabela (port)	-	-	-	-	95.55	87.73	92.64	314.14	85.46	149.77	143.27	93.77	73.24	64.99	71.61	71.47	179.71	41.29	0.93
Santa Cruz (port)	-	-	-	-	34.68	57.24	39.15	327.64	65.32	98.2	93.58	137.07	124.21	56.86	55.28	55.33	123.47	86.8	77.01
San Cristobal (port)	-	-	-	-	90.91	124.28	99.47	389.82	89.75	52.32	54.01	215.7	203.62	100.52	93.68	93.84	140.06	166.23	150.72
Seymour (port)	-	-	-	-	2.86	33.15	8.53	300.22	102.58	125.12	121.82	131.05	123.79	93.95	92.71	92.76	87.25	91.76	98.61
Baltra	95.55	34.68	90.91	2.86	-	35.51	10.27	302.77	100.18	122.5	119.18	132.42	124.78	91.81	90.45	90.5	90.11	92.25	97.94
Bartolome	87.73	57.24	124.28	33.15	35.51	-	24.91	270.96	119.44	153.7	149.64	99.81	95.2	105.94	106.96	106.96	93.04	68.56	88.56
Daphne Mayor	92.64	39.15	99.47	8.53	10.27	24.91	-	293.7	104.37	131.07	127.47	122.54	115.5	94.18	93.61	93.64	89.49	84.07	93.33
El Arco	314.14	327.64	389.82	300.22	302.77	270.96	293.7	-	383.93	424.56	420.6	223.95	245.83	366.17	369.72	369.66	271.9	272.95	314.97
Isla Gardner	85.46	65.32	89.75	102.58	100.18	119.44	104.37	383.93	-	68.21	61.32	174.58	156.08	20.49	14.66	14.76	186.26	118.95	85.09
Isla Osborn	149.77	98.2	52.32	125.12	122.5	153.7	131.07	424.56	68.21	-	6.93	231.19	215.2	86.81	79.5	79.66	188.89	176.83	149.59
Punta Suarez	143.27	93.58	54.01	121.82	119.18	149.64	127.47	420.6	61.32	6.93	-	225.47	209.23	80.03	72.75	72.9	188.11	170.91	143.06
Punta Espinoza	93.77	137.07	215.7	131.05	132.42	99.81	122.54	223.95	174.58	231.19	225.47	-	21.88	154.55	159.95	159.85	176.75	55.63	94.48
Punta Mangle	73.24	124.21	203.62	123.79	124.78	95.2	115.5	245.83	156.08	215.2	209.23	21.88	-	135.78	141.57	141.45	179.73	38.39	73.9
Bahia Post Office	64.99	56.86	100.52	93.95	91.81	105.94	94.18	366.17	20.49	86.81	80.03	154.55	135.78	-	7.42	7.25	180.3	98.96	64.63
Champion	71.61	55.28	93.68	92.71	90.45	106.96	93.61	369.72	14.66	79.5	72.75	159.95	141.57	7.42	-	0.17	178.22	104.32	71.29
La Loberia	71.47	55.33	93.84	92.76	90.5	106.96	93.64	369.66	14.76	79.66	72.9	159.85	141.45	7.25	0.17	-	178.29	104.21	71.15
Bahia Darwin	179.71	123.47	140.06	87.25	90.11	93.04	89.49	271.9	186.26	188.89	188.11	176.75	179.73	180.3	178.22	178.29	-	160.27	180.49
Bahia Elizabeth	41.29	86.8	166.23	91.76	92.25	68.56	84.07	272.95	118.95	176.83	170.91	55.63	38.39	98.96	104.32	104.21	160.27	-	42.15
Las Tintoreras	0.93	77.01	150.72	98.61	97.94	88.56	93.33	314.97	85.09	149.59	143.06	94.48	73.9	64.63	71.29	71.15	180.49	42.15	-
Punta Moreno	49.43	112.52	191.35	120.29	120.71	96.83	112.68	273.3	134.59	254.4	190.8	49.35	27.47	114.1	120.46	120.33	187.49	28.65	49.92
Punta Vicente Roca	119.96	158.49	235.79	147.89	149.58	115.23	139.39	198.36	199.68	254.4	248.89	26.31	47.95	179.86	185.03	184.93	181.95	80.99	120.68
Mosquera	98.16	38.14	92.39	0.79	3.44	32.57	8.11	299.46	103.3	125.9	122.6	130.64	123.51	94.6	93.39	93.43	86.72	91.62	98.82
Plaza Sur	98.88	24.65	70.36	23.1	20.5	54.14	29.75	323.23	84.74	102.04	98.82	147.26	137.37	79.66	76.95	77.03	101.56	102.13	99.36
Rabida	68.52	58.95	134.25	48.31	49.5	21.69	39.92	270.87	113.8	157.07	152.27	83.07	75.66	97.64	100.1	100.06	114.36	46.92	69.41
Isla Lobos	156.2	83.8	7.32	93.3	91.12	126.21	101.3	389.83	96.95	58.24	60.4	219.2	207.66	107.37	109.4	100.76	136.89	170.57	156.37
Leon Dormido	162.4	88.28	17.62	93.61	91.62	126.75	101.89	387.14	106.45	68.3	70.7	221.81	211.15	115.99	109.4	109.55	130.31	174.62	162.61
Playa Ochoa	155.57	83.33	6.4	93.19	91	126.06	101.16	389.94	96.07	57.41	59.53	218.86	207.25	106.55	99.77	99.93	137.38	170.11	155.73
Punta Pitt	193.59	118.79	46.28	119.65	117.98	152.56	128.15	404.69	135.91	87.77	91.99	249.91	240.32	146.66	139.9	140.06	138.83	204.44	193.81
El Barranco	79.39	2.93	76.59	37.35	34.96	58.72	39.67	329.38	65.23	96.08	91.58	139.8	127.06	57.66	55.72	55.78	122.66	89.69	79.76
Playa las Bachas	86.69	28.34	92.8	11.62	10.63	32.32	10.81	302.9	93.58	121.66	117.82	125.43	116.59	83.69	82.94	82.97	98.53	82.93	87.32
Punta Carrion	95.7	30.23	84.88	8.3	5.66	39.4	14.67	308.08	94.9	117	113.62	135.07	126.62	87.05	85.46	85.51	93.42	93.09	96.29
Rocas Gordon	101.49	27.37	69.57	22.88	20.37	54.73	30.05	323.1	86.91	102.57	99.52	148.81	139.22	82.16	79.35	79.43	99.35	104.22	101.98
Santa Fe	104.56	30.92	48.54	51.06	48.43	80.53	57.13	350.83	65.4	74.07	70.82	167.53	155.09	66.62	61.75	61.87	123.99	117.71	104.8
Bahia Sullivan	87.54	58.91	126.33	35.21	37.21	2.06	26.97	269.13	120.77	155.57	151.48	97.94	93.56	107.04	108.18	108.18	93.7	67.46	88.39
Puerto Egas	91.42	63.95	130.12	38.56	48.43	34.93	59	247.31	136.77	181.11	176.34	65.34	63.54	119.74	122.75	122.7	116.76	47.34	81.73
Roca Cousins	91.42	63.95	130.12	38.56	40.73	6.71	30.65	264.35	125.99	160.26	156.25	96.83	93.63	112.24	113.4	113.4	91.06	69.38	92.27
Seymour Norte	99.61	40.01	93.21	2.56	5.09	32.24	8.48	298.28	105.14	127.28	124.04	130.8	123.97	96.47	95.26	95.3	84.89	60.91	100.27
Isla Wolf	276.95	290.07	353.11	263.08	265.62	233.51	256.44	37.7	346.23	387.17	383.15	187.68	209.51	328.5	332.02	331.96	238.55	235.71	277.79

Vertex i \ Vertex j	Punta Moreno	Punta Vicente Roca	Mosquera	Plaza Sur	Rabida	Isla Lobos	Leon Dormido	Playa Ochoa	Punta Pitt	El Barranco	Playa las Bachas	Punta Carrion	Rocas Gordon	Santa Fe	Bahia Sullivan	Puerto Egas	Roca Cousins	Seymour Norte	Isla Wolf
Isabela (port)	49.43	119.96	98.16	98.88	68.52	156.2	162.4	155.57	193.59	79.39	86.69	95.7	101.49	104.56	87.54	91.42	91.42	99.61	276.95
Santa Cruz (port)	112.52	158.49	38.14	24.65	58.95	83.8	88.28	83.33	118.79	2.93	28.34	30.23	27.37	30.92	58.91	63.95	63.95	40.01	290.07
San Cristobal (port)	191.35	235.79	92.39	70.36	134.25	7.32	17.62	6.4	46.28	76.59	92.8	84.88	69.57	48.54	126.33	130.12	130.12	93.21	353.11
Seymour (port)	120.29	147.89	0.79	23.1	48.31	93.3	93.61	93.19	119.65	37.35	11.62	8.3	22.88	51.06	35.21	38.56	38.56	2.56	263.08
Baltra	120.71	149.58	3.44	20.5	49.5	91.12	91.62	91	117.98	34.96	10.63	5.66	20.37	48.43	37.21	48.43	40.73	5.09	265.62
Bartolome	96.83	115.23	32.57	54.14	21.69	126.21	126.75	126.06	152.56	58.72	32.32	39.4	54.73	80.53	2.06	34.93	6.71	32.24	233.51
Daphne Mayor	112.68	139.39	8.11	29.75	39.92	101.3	101.89	101.16	128.15	39.67	10.81	14.67	30.05	57.13	26.97	59	30.65	8.48	256.44
El Arco	273.3	198.36	299.46	323.23	270.87	389.83	387.14	389.94	404.69	329.38	302.9	308.08	323.1	350.83	269.13	247.31	264.35	298.28	37.7
Isla Gardner	134.59	199.68	103.3	84.74	113.8	96.95	106.45	96.07	135.91	65.23	93.58	94.9	86.91	65.4	120.77	136.77	125.99	105.14	346.23
Isla Osborn	254.4	254.4	125.9	102.04	157.07	58.24	68.3	57.41	87.77	96.08	121.66	117	102.57	74.07	155.57	181.11	160.26	127.28	387.17
Punta Suarez	190.8	248.89	122.6	98.82	152.27	60.4	70.7	59.53	91.99	91.58	117.82	113.62	99.52	70.82	151.48	176.34	156.25	124.04	383.15
Punta Espinoza	49.35	26.31	130.64	147.26	83.07	219.2	221.81	218.86	249.91	139.8	125.43	135.07	148.81	167.53	97.94	65.34	96.83	130.8	187.68
Punta Mangle	27.47	47.95	123.51	137.37	75.66	207.66	211.15	207.25	240.32	127.06	116.59	126.62	139.22	155.09	93.56	63.54	93.63	123.97	209.51
Bahia Post Office	114.1	179.86	94.6	79.66	97.64	107.37	115.99	106.55	146.66	57.66	83.69	87.05	82.16	66.62	107.04	119.74	112.24	96.47	328.5
Champion	120.46	185.03	93.39	76.95	100.1	109.4	109.4	99.77	139.9	55.72	82.94	85.46	79.35	61.75	108.18	122.75	113.4	95.26	332.02
La Loberia	120.33	184.93	93.43	77.03	100.06	100.76	109.55	99.93	140.06	55.78	82.97	85.51	79.43	61.87	108.18	122.7	113.4	95.3	331.96
Bahia Darwin	187.49	181.95	86.72	101.56	114.36	136.89	130.31	137.38	138.83	122.66	98.53	93.42	99.35	123.99	93.7	116.76	91.06	84.89	238.55
Bahia Elizabeth	28.65	80.99	91.62	102.13	46.92	170.57	174.62	170.11	204.44	89.69	82.93	93.09	104.22	117.71	67.46	47.34	69.38	60.91	235.71
Las Tintoreras	49.92	120.68	98.82	99.36	69.41	156.37	162.61	155.73	193.81	79.76	87.32	96.29	101.98	104.8	88.39	81.73	92.27	100.27	277.79
Punta Moreno	-	75.29	120.17	129.65	75.31	196.12	200.8	195.6	231.1	115.45	111.19	121.33	131.85	143.15	95.62	71.83	97.17	121.02	236.96
Punta Vicente Roca	75.29	-	147.4	166.12	101.61	238.79	240.6	238.52	267.54	161.09	143.78	152.89	167.4	188.29	113.22	80.42	111.09	147.28	162.48
Mosquera	120.17	147.4	-	23.88	47.98	93.95	94.21	93.84	120.16	38.07	12.01	9.09	23.64	51.84	34.63	66.99	37.93	1.88	262.33
Plaza Sur	129.65	166.12	23.88	-	64.57	72.8	74.6	72.57	102.98	22.83	22.47	15.16	2.73	28.01	56.17	86.54	60.23	25.24	286.04
Rabida	75.31	101.61	47.98	64.57	-	138.18	139.16	136.9	166.87	61.23	42.43	51.99	65.96	87.28	20.74	24.08	23.51	15.08	233.18
Isla Lobos	196.12	238.79	93.95	72.8	138.18	-	10.48	0.92	39.3	80.9	95.26	86.88	71.75	52.98	128.26	159.32	131.85	94.64	353.3
Leon Dormido	200.8	240.6	94.21	74.6	139.16	10.48	-	11.39	31.32	85.36	96.82	87.84	73.22	58.07	128.81	160.59	132.08	94.7	350.88
Playa Ochoa	195.6	238.52	93.84	72.57	136.9	0.92	11.39	-	40.13	80.43	95.04	86.71	71.56	52.48	128.11	159.1	131.73	94.55	353.39
Punta Pitt	231.1	267.54	120.16	102.98	166.87	39.3	31.32	40.13	-	115.87	124.49	114.91	101.24	89.09	154.6	187.14	157.32	120.35	369.21
El Barranco	115.45	161.09	38.07	22.83	61.23	80.9	85.36	80.43	115.87	-	28.91	29.79	20.36	28.05	60.44	85.16	65.42	39.91	291.84
Playa las Bachas	111.19	143.78	12.01	22.47	42.43	95.26	96.82	95.04	124.49	28.91	-	10.17	23.61	48.22	34.28	64.07	38.72	13.75	265.53
Punta Carrion	121.33	152.89	9.09	15.16	51.99	86.88	87.84	86.71	114.91	29.79	10.17	-	15.38	42.94	41.45	72.75	45.29	10.73	270.87
Rocas Gordon	131.85	167.4	23.64	2.73	65.96	71.75	73.22	71.56	101.24	20.36	23.61	15.38	-	28.75	56.77	87.59	60.67	24.85	285.97
Santa Fe	143.15	188.29	51.84	28.01	87.28	52.98	58.07	52.48	89.09	28.05	48.22	42.94	28.75	-	82.48	110.65	86.93	62.15	313.54
Bahia Sullivan	95.62	113.22	34.63	56.17	20.74	128.26	128.81	128.11	154.6	60.44	34.28	41.45	56.77	82.48	-	32.96	5.22	34.28	231.67
Puerto Egas	71.83	80.42	66.99	86.54	24.08	159.32	160.59	159.1	187.14	85.16	64.07	72.75	87.59	110.65	32.96	-	31.5	66.85	209.61
Roca Cousins	97.17	111.09	37.93	60.23	23.51	131.85	132.08	131.73	157.32	65.42	38.72	45.29	60.67	86.93	5.22	31.5	-	37.38	226.92
Seymour Norte	121.02	147.28	1.88	25.24	15.08	94.64	94.7	94.55	120.35	39.91	13.75	10.73	24.85	62.15	34.28	66.85	37.38	-	261.18
Isla Wolf	236.96	162.48	262.33	286.04	233.18	353.3	350.88	353.39	369.21	291.84	265.53	270.87	285.97	313.54	231.67	209.61	226.92	261.18	-

APPENDIX 14. TOURIST TRANSPORT DEMAND IN NUMBER OF PASSENGERS PER PORT

Port	Demand (amount of people)
Santa Cruz	607
San Cristobal	352
Seymour	660
Isabela	166

APPENDIX 15. EXAMPLE OF A TOURIST ROUTE WITH THE MDPVRP SOLUTION. ROUTE PERFORMED BY ANGELITO I



APPENDIX 16. 80% OF DEMAND IN NUMBER OF PASSENGERS PER PORT

Port	Demand (amount of people)
Santa Cruz	486
San Cristobal	282
Seymour	528
Isabela	133

APPENDIX 17. MDPVRP MODEL RESULTS WITH 80% OF THE DEMAND.

Vessel Name	Route
Aida Maria	P.Baquerizo Moreno-17-12-20-32-21-23-5-18-34-31-4-6-8-P. Seymour
Albatros	P. Seymour-5-23-32-10-33-34-30-31-6-4-19-8-18-P. Seymour
Amazonia	P. Ayora-10-32-21-23-19-8-34-6-4-31-22-5-18-P. Seymour
Anahi	P. Seymour-34-30-4-6-31-19-8-18-5-23-21-32-10-P. Ayora
Angelito I	P.Baquerizo Moreno-20-12-33-21-34-18-5-23-19-8-6-4-31-P. Seymour
Archipell II	P. Seymour-18-34-30-31-4-6-8-19-5-23-21-32-10-P. Ayora
Coral II	P. Villamil-16-3-11-15-7-10-32-21-23-19-8-34-18-P. Seymour
Daphne	P. Seymour-18-34-30-31-6-4-10-32-21-23-19-8-5-P. Seymour
Darwin	P.Baquerizo Moreno-20-12-17-33-21-10-32-23-5-19-8-34-18-P. Seymour
Deep Blue	P. Seymour-5-18-34-8-19-23-21-32-10-33-17-12-20-P.Baquerizo Moreno
Eden	P. Seymour-5-19-32-23-21-33-4-6-31-22-30-34-18-P. Seymour
Evolution	P. Villamil-16-30-31-4-6-8-19-21-32-23-5-34-18-P. Seymour
Flamingo I	P.Baquerizo Moreno-12-20-32-21-23-5-18-34-30-4-31-6-8-P. Seymour
Fragata	P. Seymour-18-8-6-31-22-4-21-23-5-34-12-17-20-P.Baquerizo Moreno
Galapagos Adventure	P. Villamil-16-30-31-6-4-19-8-34-32-21-23-5-18-P. Seymour
Galapagos Adventure II	P.Baquerizo Moreno-17-12-20-32-23-5-34-6-4-31-19-8-18-P. Seymour
Galaxy	P.Baquerizo Moreno-20-27-10-32-21-23-33-4-6-30-34-18-5-P. Seymour
Golondrina I	P. Seymour-5-34-30-31-22-6-4-21-32-23-19-8-18-P. Seymour
Gran Monserrat	P. Seymour-18-8-6-4-31-19-21-23-5-34-17-12-20-P.Baquerizo Moreno
Integrity	P. Seymour-18-34-8-6-4-19-23-32-21-33-20-12-17-P.Baquerizo Moreno
Jesus del Gran Poder	P. Seymour-18-5-23-32-10-19-8-34-6-4-12-17-20-P.Baquerizo Moreno
Mary Anne	P. Ayora-10-32-21-23-5-19-33-4-6-31-30-34-18-P. Seymour
Millenium	P. Ayora-32-21-23-19-8-6-4-31-22-30-34-5-18-P. Seymour
Monserrat	P. Seymour-8-6-31-22-4-21-23-5-18-34-17-12-20-P.Baquerizo Moreno
National Geographic Islander	P. Villamil-16-2-30-34-22-31-4-6-8-19-23-21-32-P. Seymour
Reina Silvia	P. Ayora-10-32-21-23-19-33-31-4-6-8-34-18-5-P. Seymour
Samba	P. Seymour-5-18-34-30-31-6-4-8-19-23-21-32-10-P. Ayora
Sea Finch	P. Ayora-10-32-21-19-5-23-33-4-31-6-30-34-18-P. Seymour
The Beagle	P.Baquerizo Moreno-17-12-20-19-23-21-33-4-6-8-34-18-5-P. Seymour
Tip Top IV	P. Seymour-18-8-6-4-31-21-32-23-5-34-17-12-20-P.Baquerizo Moreno
Xavier III	P. Seymour-5-18-34-8-19-23-32-21-10-33-17-12-20-P.Baquerizo Moreno
Yolita II	P.Baquerizo Moreno-17-12-20-32-21-23-5-34-31-22-4-6-8-P. Seymour

APPENDIX 18. 50% DEMAND IN NUMBER OF PASSENGERS PER PORT

Port	Demand (amount of people)
Santa Cruz	304
San Cristobal	176
Seymour	330
Isabela	83

APPENDIX 19. MDPVRP MODEL RESULTS WITH 50% OF THE DEMAND.

Vessel Name	Route
Aida Maria	P.Baquerizo Moreno-17-12-20-32-21-23-33-4-6-31-30-34-18-P. Seymour
Albatros	P. Villamil-25-24-29-31-33-19-23-32-10-4-6-30-34-P. Seymour
Amazonia	P. Ayora-10-32-21-23-8-19-33-31-6-4-22-30-34-P. Seymour
Anahi	P.Baquerizo Moreno-12-20-17-31-33-19-32-26-14-4-30-34-18-P. Seymour
Angelito I	P. Villamil-25-24-29-31-33-19-32-23-17-4-6-30-34-P. Seymour
Archipell II	P.Baquerizo Moreno-17-12-20-32-23-19-33-4-6-30-34-18-5-P. Seymour
Coral II	P.Baquerizo Moreno-20-12-33-23-19-10-32-27-26-14-22-30-34-P. Seymour
Daphne	P. Villamil-25-24-29-31-33-19-23-32-26-4-30-34-18-P. Seymour
Darwin	P. Seymour-14-9-31-33-19-27-17-12-8-4-30-34-18-P. Seymour
Deep Blue	P. Seymour-5-18-34-30-6-4-33-32-23-19-10-27-20-P.Baquerizo Moreno
Eden	P. Seymour-5-23-21-32-10-19-33-22-14-4-30-34-18-P. Seymour
Evolution	P.Baquerizo Moreno-20-10-27-19-23-32-33-4-22-34-31-6-8-P. Seymour
Flamingo I	P.Baquerizo Moreno-20-12-33-23-19-10-27-29-9-14-22-18-34-P. Seymour
Fragata	P. Ayora-10-32-21-23-19-8-6-31-4-30-34-18-5-P. Seymour
Galapagos Adventure	P. Seymour-8-6-31-22-33-19-32-21-9-14-4-30-34-P. Seymour
Galapagos Adventure II	P. Seymour-5-18-34-30-6-4-33-19-16-23-21-32-10-P. Ayora
Galaxy	P. Ayora-7-27-10-19-32-23-33-4-6-30-34-18-5-P. Seymour
Golondrina I	P.Baquerizo Moreno-20-12-33-23-19-10-27-21-14-4-30-34-18-P. Seymour
Gran Monserrat	P. Ayora-10-32-21-23-8-19-33-31-4-6-30-34-18-P. Seymour
Integrity	P. Seymour-18-8-6-14-22-30-4-33-21-10-32-23-5-P. Seymour
Jesus del Gran Poder	P. Seymour-18-34-30-22-33-19-23-10-32-27-17-12-20-P.Baquerizo Moreno
Mary Anne	P. Seymour-34-8-14-22-33-19-23-32-10-27-30-4-6-P. Seymour
Millenium	P.Baquerizo Moreno-20-27-10-19-23-32-33-4-31-22-30-34-18-P. Seymour
Monserrat	P. Villamil-25-24-29-31-33-19-2-32-6-4-22-30-34-P. Seymour
National Geographic Islander	P. Villamil-16-30-14-34-22-31-4-33-32-21-23-5-18-P. Seymour
Reina Silvia	P. Seymour-34-18-32-21-10-19-23-5-8-30-6-4-31-P. Seymour
Samba	P. Ayora-10-17-20-32-21-23-4-31-6-30-34-18-5-P. Seymour
Sea Finch	P. Ayora-21-10-27-19-32-23-33-4-31-30-34-5-18-P. Seymour
The Beagle	P.Baquerizo Moreno-12-17-20-19-32-23-33-4-6-30-34-5-18-P. Seymour
Tip Top IV	P.Baquerizo Moreno-20-12-27-19-32-23-33-4-6-30-34-18-5-P. Seymour
Xavier III	P. Seymour-14-9-31-33-19-27-23-28-32-4-22-30-34-P. Seymour
Yolita II	P. Ayora-7-20-19-32-23-33-4-6-31-9-14-18-34-P. Seymour

APPENDIX 20. DEMAND IN NUMBER OF PASSENGERS PER ROUTE

Route	Demand (number of people)
1	183
2	168
3	120
4	451
5	38