UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingeniería Politécnico

The Cargo Transport System of The Galapagos Islands: An Analysis from a Logistic Perspective on its Capacity to Fulfill Cargo Demand

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RESUMEN

Las Islas Galápagos es una de las 24 provincias del Ecuador y están ubicadas en el Océano Pacífico, aproximadamente a 1000 km de la línea costera del continente. Algunos de los títulos que este lugar ostenta son: Parque Nacional (1959), Herencia Natural del Mundo (1978) y Reserva de la Biósfera (1985). Las Islas dependen significativamente del sistema de transporte de carga marítima desde el continente, un servicio que es supervisado por autoridades públicas, pero cuya ejecución se da gracias a navieras independientes y un operador portuario. En el pasado, se han hecho estudios acerca del movimiento de carga hacia las Islas, pero los mismos se encuentran desactualizados en términos de niveles de carga y la naturaleza de los procesos requeridos para movilizar la misma hacia las Islas. Este estudio tiene la intención de entender el estado actual del sistema, en particular el manejo de carga contenerizada. Adicionalmente, el modelo de ruteo de vehículos heterogéneos con costos dependientes de los mismos se adapta al contexto de las Islas con el objetivo de determinar el ruteo de embarcaciones que permita cumplir con la demanda de carga mientras se minimizan los costos de flete. De esta manera, la capacidad del sistema es analizada desde una perspectiva logística y matemática, con el fin de proveer recomendaciones para mejorar el sistema de transporte de carga a las Islas Galápagos.

Palabras clave: carga, contenerizada, Galápagos, VRP, logística, procesos

ABSTRACT

The Galapagos Islands is one of the 24 provinces of Ecuador and are located in the Pacific Ocean, approximately 1000 km from the coastline of the continent. Amongst the many titles the site flaunts, some of them are: National Park (1959), Natural World Heritage (1978) and Biosphere Reserve (1985). The Islands depend significantly on the maritime cargo transport system from the continent, a service that is overseen by public authorities but performed by private shipowners and a port operator. Previous studies have been done regarding the movement of cargo to the Islands but remain outdated in terms of levels of cargo and the nature of the processes to bring cargo to the Islands. This study aims to understand the current state of the system, in particular the handling of containerized cargo. Additionally, a heterogeneous vehicle routing problem with vehicle-dependent costs is adapted to the context of the Islands in order to minimize non-capacity dependent fleet costs. In this manner, the capacity of the system is analyzed from both a logistic and mathematical standpoint, in order to arrive to recommendations to improve the cargo transport service to the Islands.

Key words: cargo, containerized, Galapagos, VRP, logistics, processes

TABLE OF CONTENTS

1. INTRODUCTION

The Galapagos Islands is one of the 24 provinces of Ecuador and they are located in the Pacific Ocean, approximately 1000 km from the coastline of the continent. Amongst the many titles the site flaunts, some of them are: National Park (1959), Natural World Heritage (1978) and Biosphere Reserve (1985) (Ecogal, n.d.). The archipelago comprises 19 islands, of which 3 contain the majority of inhabitants (Consejo de Gobierno del Regimen Especial de Galapagos, 2016). According to the 2015 census, Santa Cruz Island has the highest population with 15,701 people, followed by San Cristobal with 7,199 people and lastly, Isabela with 2,344 people (Instituto Nacional de Estadística y Censos, 2015). The many different titles associated to the Galapagos Islands evidence its relevance in the global scenery and reveal the complex human mobilization process that results from high volumes of tourists. During the period between 2007 and 2014, the accumulated growth rate of tourists was 3.7% (CGREG, 2015). Such growth has had a significant effect over the infrastructure offered to tourists in the islands, which is evidenced by the 210% increment in the hotel sector during the same period (CGREG, 2015).

With the rapid expansion of tourism infrastructure, the need for supplies has also increased substantially. In 2011, ships carried between 800-900 tons of goods per trip, comprising: 60% construction materials, 20% dry food and grains, 10% fresh produce, and 10% miscellaneous cargo (Brewington et al, 2012). In a study completed in 2016, it was determined that 1,700 tons of goods were transported per trip, illustrating the rapid increment in demand for maritime cargo transport (Salazar, 2016). From the perspective of the community, such increment has ocurred without adequate supporting processes, resulting in complaints such as ill treatment of cargo during loading/unloading procedures, lack of organization of cargo types onboard, and deficient port infrastructure (CGREG, 2012). From the perspective of the government institutions overseeing port operations, all agree that actions should be taken to improve relevant infrastructure. In 2015,

the Consejo de Gobierno del Regimen Especial de Galapagos (CGREG), a governmental institution responsible for the administration of the Islands, issued the Plan for the Sustainable Development and Territorial Organization of the Galapagos Province 2015-2020. One of the regional objectives determined within this plan includes the improvement of port infrastructure for cargo processing (CGREG, 2015).

The processes and institutions surrounding the transit of cargo from the continent to the islands change throughout the years as new policies are enforced upon its participants. Until 2017, the following three independent shipowners were in charge of receiving, loading, and transporting the goods according to a 21-day itinerary: Transnave, Pacific Cargo Line and Corsamer (Salazar, 2016). In October of 2017, Panatlantic – Logistics S.A. won the public tender for the administration of the ports in Guayaquil City destined to maritime cargo shipping between the islands. This means that they are now the only ones in charge of the following phases: reception, classification, palletization, loading and unloading operations (J. Tapia, personal communication, February 18, 2020). Since the introduction of the new port operator, there have not been new studies to analyze the current state of the processes they handle, nor if there has been a fluctuation in the frequency of each cargo type.

The objective of the following study is to build a perspective about the state of the processes previously mentioned, retrieving data related to the movement of the different types of containerized cargo to the Islands, all in an effort to understand the current state of the cargo transport system. It is worth noting that the focus of the study is containerized cargo which is only received in two of the archipelago's islands: Santa Cruz and San Cristobal.

The added value of the study can be found firstly in its alignment to the perspective and necessities of the different parties affected by cargo transport. In the case of the Galapagos community, an

update on the state of the internal processes of the system is required in order to assess the validity of their claims. In the case of regulating institutions, the objectives in the sustainable development plan regarding the improvement of cargo transit require a clear understanding of the strengths and weaknesses of the whole system. Secondly, the studies analyzing the perception of the Galapagos community and the state of the system are outdated and limited. The first one was last observed in 2012 by a government-run initiative, while the latter was partially recorded in studies up to 2018. Therefore, the present study aims to fulfill the discontinuity of information regarding the cargo transport system between the continent and the Islands by means of the following objectives. First, characterize the current state of the macroprocesses involved in cargo handling in the container yards of Guayaquil, Santa Cruz and San Cristobal. Second, analyze cargo manifests provided by the port operator, pertaining to the period between January 2018 and December 2018, to understand how the movement of cargo has changed throughout the years. Additionally, data provided by the Ministerio de Transporte y Obras Públicas [Ministry of Transportation and Public Works] (MTOP) is also used to further understand the levels of cargo in 2018 and the first half of 2019. Third, propose a model for the optimal routing of ships in order to fulfill the demand of cargo while minimizing fleet costs. Fourth, establish recommendations for the strengthening of the logistic processes and, based on the model´s results, for the current fleet. Literary Review

The literary review is divided in two main sections. The first, focuses on the most relevant studies that were developed during the last decade regarding the processes within the cargo transport system to the Islands and pertinent factors affecting its stability. The second, considers mathematical models concerning the optimization of factors affecting liner shipping operations in order to improve fleet costs. By assessing the background of existing processes and the potential

application of mathematical optimization models based on real data, this study aims to arrive at an optimal solution for the improvement of the system.

2. LITERARY REVIEW

2.1 Previous studies on the state of maritime cargo transportation between The Galapagos Islands and Ecuadorian continental territory

At the beginning of the last decade, several interesting studies were developed on the conditions surrounding the cargo[1] with destination to Galapagos. One of them came about in 2012 when WildAid[2] designed a study revealing the biosecurity weaknesses in the cargo transportation to the Island. In this year, the port named Store Ocean, located in the area called La Pradera in Guayaquil, was the only port accommodated to receive cargo headed to the Islands. Such was organized as loose cargo, no pallets, and many times without undergoing inspection by Agencia de Bioseguridad de Galapagos [Agency for the Biosecurity of the Galapagos] (ABG)[3] given the overwhelming quantity of loose items. Additionally, it was estimated that around 60,000 tons of goods were moved annually by the 4 ships habilitated during the time frame of the study. The research paper also included estimates of different scenarios regarding the projected growth of cargo until 2040. These approximations reveal the delicate conditions in which the system was growing and the resources it needed to continue functioning. Some of these included: one additional ship of 1,400 to 1,500 tons of capacity and the reduction in loading/unloading times in Galapagos ports and/or Guayaquil ports (Brewington et al, 2012). Although the study provided a

[1] The cargo of interest in the present study is defined as groceries, gas, lubricants, and general goods (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016).

[2] WildAid is a conservation group that works with governments to protect fragile marine reserves, amongst its many efforts to reduce global consumption of wildlife products (WildAid, 2018)

[3] ABG is the government institution assigned to the inspection of cargo sent to the Galapagos in order to warrant the conservation of the Galapagos ecosystem

sturdy outlook of the procedures and infrastructure that would be required to fortify the biosecurity chain of products to the Islands, the logistic weaknesses of the system are only briefly reviewed to offer a couple recommendations.

In 2012, a study was done by CGREG in which the perceptions of business owners regarding the transportation of cargo was recorded. Most of the complaints reveal that users of the maritime cargo transport services think that the majority of damages to the cargo result from the loading/unloading operations and conditions of maritime transportation. Additionally, they believe that dockworkers that participate in these operations should receive training to avoid the mishandling of cargo (CGREG, 2012). The study mainly served as the voice of a relevant stakeholder of the system to prioritize which processes needed tackling.

In 2016, the Plan for the Sustainable Development and Territorial Organization of the Galapagos Province 2015-2020 was published. It established a diagnosis of the key factors affecting the sustainable growth of the Islands, some of the most relevant aspects of the study are threats to its ecosystem, population growth, and tourism. These three factors shape the way the cargo transport system works, as it must ensure the protection of the ecosystem while serving growing demand due to population and tourism growth. The latter presents an additional challenge to the cargo transport system, as the hotel sector and other infrastructure require further supplies from the mainland to accommodate tourists. The analysis of these circumstances revealed added pressure on the straining resources to transport cargo to the Islands. Besides analyzing these factors, in order to mitigate their impact on the Islands, the plan constituted five strategic objectives to achieve by 2020. The most compatible with the present study is objective four, which aimed to reduce the dependence on the continent by optimizing transportation, among others. More specifically, this objective intended to improve the management of port operations and the

available infrastructure (CGREG, 2016). The intent of the current study aligns with the objectives set in the plan, as it attempts to understand the current state of port operations and how it is responding to existing demand.

In 2016, a thesis was published by a masters' student at the University of Guayaquil pertaining to the improvement of the process of unloading containers in the ports of Santa Cruz and San Cristobal. The study focuses on the limitations the ships have to face due to the lack of adequate ports in the Islands and the resulting restrictions in port operations. One of the most valuable aspects of the work is the contextualization of the problem, where it discloses the authorities involved in the system, valuable terminology, and data on the monthly tons of cargo that arrive to the islands. The study proposed the purchase of a 25-ton crane and a larger boat to unload containers from the ships, thus reducing the loading/unloading times from 16 to 3 days (Salazar, 2016). From a strictly logistic standpoint, the reduction in cycle time endorsed by this solution is significant, but the scenario considered does not reflect the reality of the system. Firstly, the author did not mention the cost of implementation, which could represent a momentous investment. Secondly, the clash of interests associated to the cargo transport system interfere with any changes in infrastructure, given that it's not clear who exactly would have to pay for the equipment. Finally, without a sound consideration of the state of all the processes affecting the total cycle time of the system, optimization is not complete.

In 2018, an article was published by the official journal of Universidad del Pacífico in Ecuador, in which the weaknesses of the ports in Galapagos are revealed in respect to containerized cargo. Geographical attributes of each port were considered, highlighting their inability to sustain container ships due to their shallow waters. Also, the author dedicated a significant section to summarize relevant points of the resolution provided by the Subsecretaría de Puertos y Transporte

Marítimo y Fluvial (SPTMF)[4] to govern maritime cargo transport between the Islands and the continent. Such is directed to shipowners and port operators, detailing the macro processes they should abide by, but no precise regulation over the internal procedures each decide to adhere to. Additionally, the author superficially described the processes that should be developed in order to support the logistical challenges of the system. These included: reception and dispatch of cargo, loading of containers, and inland transportation of cargo (Mazón, 2018). Currently, these processes are handled by the existing port operator, and have yet to be exposed in literature.

As this review confirms, the most recent research has concentrated on revealing the external factors that affect the sustainability of the islands and providing partial data of the cargo transport system between continent and the islands. Important conclusions, such as the impact of the growth of tourism in the system and the weaknesses relating to infrastructure, have been established. However, none of the studies mentioned produced research on the numerous processes that govern the logistic activities that develop at the operational level in the ports of Guayaquil and Galapagos. Given the introduction of the current Port Operator in November of 2017, the handling of cargo has progressively changed and there is a need to assess the ongoing state of the system.

2.2 Optimization models applied to liner shipping operations

The system of interest in the present study is dependent upon a mode of transport referred to as liner shipping, which is described as "the service of transporting goods by means of high-capacity, ocean-going ships that transit regular routes on fixed schedules" (World Shipping Council, n.d). According to the 2019 United Nations Secretary-General Report on International Trade and Development, the top 10 shipping lines in the world account for 83% of the maritime

[4] The SPTMF is the branch of the Ministry of Transportation in charge of guiding, establishing and coordinating marine policy in Ecuador (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016).

transport sector (United Nations Commission of International Trade and Development, 2019), exposing the constrained market in which liners around the world must perform.

Studies completed between 2008 and 2011 agreed on the elevated costs that characterize liner shipping operation[5]. Fleet costs is one of two components considered in the cost structure of shipowners, which sub-components are detailed in annex A. The other component, cargo-handling, includes loading/unloading activities, transshipment of cargo, and the daily cost of owning or leasing containers. In particular, it is noted that carriers have an incentive to maintain an effective use of their capacity and fuel by keeping low speeds, given that the latter represents up to 50% of the fleet costs and the first affects both operational and capital cost (Brouer et al, 2013).

Along with understanding the cost structure of liner shipping, the hierarchy of decisions is also a factor that defines the type of optimization models that are applied. Meng et al. explains the nature of each set of decisions as the following. First, strategic planning stands at the top, as it covers long-term decisions such as determining the size and sort of the fleet, alliances with other liner companies and network design. Second, tactical planning deals with determining service frequency, deploying ships and aligning sailing speed with arrival/departure schedules. Finally, operational planning arranges cargo routing and ship rescheduling to meet demand, while assigning the necessary crew (Brouer et al, 2013).

Considering the context previously identified, the increase in routing and scheduling optimization problems on liner container shipping seems reasonable, as there are many aspects to regulate in order to attain an efficient operation. In the past, most of the research focused on industrial and tramp shipping [6], perhaps due to the reluctancy of global liner companies to share

[5] Veldman, 2011 - cites a source from 2008 for a table of costs according to number of TEU
Brouer et al, 2013 - cite a source from 2009 to establish a cost structure for liner shipping
Moon & Woo, 2014 - cite a source from 2011 for a table of costs according to number of TEU

[6] Industrial shipping: "...operator owns the cargoes and controls the fleet, trying to minimize the cargo transportation cost" (Homsi et al, 2019)

their data (Meng et al, 2014). This justifies the limited studies published in the last decade tackling the subject of ship and cargo routing. Even more so, studies focusing on liner shipping in island settings or comparable systems are scarce. Nevertheless, an overview of studies regarding the optimization of fleet costs in liner shipping is bound to shine a light on the cargo transport system object of this study.

In 2008, Agarwal and Ergun publish their study on ship-scheduling and cargo routing with a given demand and set of ports, optimizing profitability by choosing the most convenient routes. They use a mixed-integer programming model considering weekly frequency and transshipment of cargo between service routes. Given the large size of the problem studied, three different solution algorithms were applied, obtaining high capacity utilization and transshipment movements. The models minimized the operating costs of routing ships in the selected cycles, also including the revenue associated to each.

In 2009, Yan et al published an article proposing a ship scheduling and container shipment planning model while minimizing the system's costs. Fixed costs and indirect costs were not considered, thus the profit that was maximized corresponds to short term operating profit. Time-space networks were used for ship and container planning, where each time period was considered as the round-trip around designated ports, named *voyage*, and a *service* was considered as a designated number of voyages. After formulating the problem as an integer multiple commodity network flow problem, the authors used Lagrangian relaxation with sub gradient methods and designed a solution algorithm to determine a lower and upper bound of the optimal solution. Translating the model to a Taiwanese marine shipping company, the service rate improved by

Tramp shipping: "...operator follows the availability of cargoes in the market, often transporting a mix of mandatory and optional cargoes with the goal of maximizing profit" (Homsi et al, 2019)

7.55% and the operating profit by 16.69%, managing to route containers more cost-efficiently. This model considered a weekly service and transshipment points (moving containers between ships during a voyage). The first condition is not standardized within the current system, causing for ships to arrive to ports on different days each week. The second condition occurs at port arrival by third-party feeder barges, whose operations are not part of this study.

In 2013, Brouer et al. published a proposal for a benchmark suite for liner shipping network design, a reference model meant to garner the base aspects of the liner shipping business for others to mold to their need. Besides describing a detailed cost structure, the study considers different types of vessels and ports within regions, allowing for sizable networks to be represented. Additionally, the paper describes the use of the variations for the vehicle routing problem (VRP) in several studies where capacity and ship routing are tackled to optimize costs. Mainly, VRP models with variation in size and type of vessels is determined as a viable base model. The considerable knowledge the authors of the paper had of the liner shipping business allow for a deep understanding of the factors that may affect any form of optimization.

In 2007, Baldacci, Batarra and Vigo publish a paper on the different approaches to the vehicle routing problem, considering the different variants base on cost adaptation and fleet and size mix variety. The study expands on the different lower bounds applied to the problem which, by its combinatorial nature, is np hard when considering numerous ports and vehicle types. The basic formulation for a heterogeneous VRP with vehicle dependent routing costs depends on a set of nodes and arcs, representing the ports and different routes to each from the hub port. Parameters for demand per node and capacity per vehicle are included, as wells as constraints that limit the number of vehicles that visit each node and the amount of cargo each ship is able to carry.

The studies reviewed reveal the necessity of adapting a ship and cargo routing model to the needs of the system of interest, which is composed of two nodes and 3 types of ships. Although the size of the problem may seem insignificant next to the contexts analyzed in the previous papers, implementing a model is relevant to understanding the capacity of system.

3. METHODOLOGY

During the review of literary material regarding the cargo transport system between the continent and the Galapagos Islands, it was evident that there was a limited amount of updated information about the current state of the internal processes. Therefore, it became vital to resort to as many resources possible in order to answer the following questions:

- ❑ What is the overall process that individuals forego in order to send cargo to the Islands?
- ❑ What are the internal processes that occur upon the reception of cargo and which authorities or institutions have a bearing upon them?
- ❑ What are the itineraries, routes and ships assigned to the task?
- ❑ Which costs are associated with the transportation of the cargo?
- ❑ What historical data is there about the amounts of each cargo type transported?

In order to tackle the main goal of the study, the methodology chosen as the backbone of the research was Dr. Frederick S. Hillier's & Phases for an Operations Research Study:

1. Define the problem of interest and gather relevant data
2. Formulate a mathematical model to represent the problem

3. Develop a computer-based procedure for deriving solutions to the problem from the model
4. Test the model and refine it as needed
5. Prepare for the ongoing application of the model as prescribed by management
6. Implement

Given the limited time frame of the study, the methodology was followed up to stage 4 where the model was evaluated with the data and assumptions initially determined but not prepared for implementation in the real system.

As Dr. Hillier states in the 10th edition of his textbook Introduction to Operations Research, understanding the underlying factors that encompass the problem at hand is the phase on which most time is spent and whose precision and accuracy results crucial (Hillier & Lieberman, 2015). To provide an in-depth comprehension of the data concealed within these questions, and given the limited time frame of the study, the following qualitative methods were chosen: interviews, participant observation and collection of existing data.

The most important resource to obtain was the access to the ports in Guayaquil and Galapagos, as it made available all the data needed to answer the research questions through interviews and participant observation. Such access was provided by the chief of logistics of Panismar[7] , the engineer Juan Carlos Tapia, during a six-day visit in February to the ports in La Pradera-Guayaquil, and the ports in San Cristobal and Santa Cruz-Galapagos. The interviews were semi-structured using the main research questions detailed previously. Nevertheless, relevant information was recorded from open conversations without a structured format, which were held with several workers within the facilities. The participant observation was conducted within these

[7] WildAid is a non-profit organization that works with governments to prevent illegal wildlife trade. Their involvement in Galapagos has been towards invasive species awareness and reduction.

visits with the objective of understanding the actual activities involved in the reception, palletization, inspection, and loading/unloading of cargo. Such was recorded in some cases and, in all cases, notes were taken. Finally, existing data was gathered from the archives of Panismar, in particular the cargo manifests, where information is recorded regarding cargo sent in every ship sent to the Islands. Following the application of the methods described, the most important information was transcribed in order to extract relevant aspects regarding the research questions

Additionally, existing data was gathered from multiple governmental institutions such as CGREG, ABG, and MTOP, with the intention of grasping the evolution of the transportation of cargo to the Islands in the last decade and the factors related to infrastructure or population that have influenced it.

4. DATA COLLECTION

In the upcoming sections, data collected during the visits to port facilities in Guayaquil, Santa Cruz and San Cristobal is detailed. The first section clarifies the roles of important entities that have a direct influence over the system. The second section provides background information of the port operator and its operations. The third section describes the macro processes individuals must undergo to send cargo to the Islands. The fourth section describes the update on data regarding cargo movement towards the Islands. The fifth section outlines the mathematical model adapted to the systems characteristics.

4.1 Competencies of parties involved

Consejo de Gobierno del Regimen Especial de Galapagos (CGREG): Institution responsible for the administration of the Special Regime of the Galapagos Province, which functions as a technical secretary of the main government (Art. 258, Constitución de la República del Ecuador). This institution loans container yards in Guayaquil and the Islands to the port operator through a gratuitous bailment contract. This allows CGREG to restrict any infrastructure changes that the port operator may execute in the yards (J. Tapia, personal communication, February 18, 2020). Additionally, given that maritime cargo transportation is regulated by the state (Art. 314, Constitución de la República del Ecuador), CGREG is the designated authority to oversee port operations related to the Islands cargo transit.

Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galapagos (ABG): Institution responsible for the conservation of the ecosystems within The Galapagos Islands, regulating the various means through which non-native or prohibited species or items may enter. According to its strategic objectives, the institution is able to position personnel in ports in order to inspect cargo and retain those items that do not abide to regulations (Estatuto Orgánico de Gestión Organizacional por Procesos de la ABG of 2013).

Subsecretaría de Puertos y Transporte Marítimo y Fluvial (SPTMF): Branch of the Ministry of Transportation in charge of guiding, establishing and coordinating marine policy in Ecuador. Within the cargo transport to the Islands, the institution regulates shipowners and port operators, ensuring that they adhere to their obligations and follow macro processes governing the handling of cargo. Additionally, it establishes the schedules each authorized ship must follow and the routes.

Currently, each ship begins a round-trip approximately 12 days after the previous ship has sailed (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016).

Shipowners: Private shipowners are subject to the regulation of SPTMF and should follow three main guidelines: abide to the itinerary of routes and frequencies determined by the SPTMF, maintain updated the necessary documents for the operation of the ships, and present the cargo manifest to the port captaincy and the SPTMF. Additionally, shipowners are in charge of loading/unloading containers and transporting them to the destinations according to the authorized routes (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016). Currently, there are 2 shipowners authorized to provide cargo transport service to the Islands: Pacific Cargo Line and Transnave. The latter is a state-owned shipowner.

Port Operator: Private entity in charge of the consolidation and reception of cargo (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016). Their operations occur in the container yards loaned by CGREG, which include reception, palletization, consolidation, loading/unloading, and dispatch of cargo. They work under a gratuitous bailment contract with a duration of 2 years, after which they may enter a public tender to extend their contract. Within the contract, the tariff they may charge for their logistic services is defined by CGREG (J. Tapia, personal communication, February 18, 2020).

Shipper and recipient: The shipper is known as the person or entity that delivers the goods for transportation to the Islands, where the recipient claims the goods. Recipients may hire more than

one shipper to deliver the cargo, as well as another third-party to receive the cargo in the Islands (F. Rivas, personal communication, February 28, 2020).

4.2 Panismar: background and current stance

Panismar is the current port operator of the cargo transport system of The Galapagos Islands appointed to the administration of port facilities in the Islands and Guayaquil. Its operations began in November 2017 after CGREG terminated the gratuitous bailment contract with the last port operator, RFS, due to a breach of contract terms such as industrial safety and sanitation conditions (El Universo, 2017). The current contract has a duration of 2 years, during which Panismar is given the container yards in Guayaquil and the Islands to control all the processes regarding the handling of cargo prior to transportation between the continent and Islands. As part of the contract, tariffs were negotiated with CCREG, allowing Panismar to charge the public 40% of the freight value for logistic activities in the case of containerized cargo and 20% for loose cargo (J. Tapia, personal communication, February 18, 2020). Additionally, CGREG must approve any changes in infrastructure before they are implemented. Although the port operator has improved the state of the facilities received in 2017, it refuses to generate any further expenditures, as the return of the investment is not obtainable within the limited duration of the agreement. In the month of March 2020, the contract reaches to an end and, currently, Panismar awaits the results of the new tender in which they participated with the condition of extending the contract to 5 years (J. Tapia, personal communication, February 18, 2020).

The port operator must work alongside the authorized shipowners and has no authority over their internal processes, which mainly restrains their own process of cargo reception. The importance of this factor will become evident when this process is explained in subsequent sections.

4.3 Processes governing cargo handling

The following section describes the processes managed by the port operator regarding cargo handling. In the annexes N through Q, diagrams for the most relevant processes have been included. Given that the objective of the diagrams is to provide guidance to the general public about these processes, they are in Spanish.

As annex B illustrates, cargo goes through 7 macro processes, where the shipowners and the port operator collaborate to serve the public. This study excludes process 4, as the involvement of the port operator in it is minimal. The information detailed below is a result of the active observation and conversations with personnel performed during the visits to the container yards in Guayaquil and the Islands. It is necessary to disclose to the reader that the processes presented below have yet to be revised with pertaining authorities to ensure that they are completely accurate.

4.3.1 Cargo reception.

The reception of cargo works according to a 10-day itinerary which allows the port operator to distribute the delivery of goods by customers in a manner that favors storage and conservation of products. The shipowners are the first point of contact with the client, as they receive a list of the goods that will be sent, and they charge according to the rates established by the Ministry of Transportation in a 2011 resolution (Tarifas para el Transporte Marítimo de Cabotaje entre Guayaquil y la Provincia de Galapagos y Viceversa of 2011). Next, the client approaches the administrative office of the port operator, who charges the tariff for logistics and verifies permits for dangerous merchandise.

Next, in the area for cargo reception, clients await their turn until personnel verify the veracity of the items described in the invoice. Here, port operator supervisors revise that the packaging favors a safe handling of the cargo, followed by inspection activities by CCREG and

ABG supervisors. To complete the process, 2 labels are attached to each package. One is a color-coded tag that identifies the destination of the cargo and the initials of the recipient. The other, contains information of the items sent and the recipient. Finally, the client signs a copy of the invoice and the cargo is located in the warehouse according to its final location and cargo type.

The process previously described applies for containerized cargo headed to Santa Cruz and San Cristobal. The process to receive cargo headed to Isabela and Floreana is different because these Islands only receive loose cargo. The first point of contact in this case is port operator personnel at the warehouse assigned for cargo heading to these islands. Here, the cargo is simultaneously verified by the shipowner, the port operator and CCREG/ABG authorities. The shipowner generates a detail of the cargo, which the client then takes to the port operator to pay for the logistics tariff. The cargo is stored according to its destination and cargo type.

An additional exception in the cargo reception process occurs during the last day of the 10-day itinerary, where perishable goods are received. The difference is evidenced when the client approaches the warehouse where the cargo is verified, given that they enter the container yard to deliver the cargo directly to the containers. Here, a port operator supervisor registers the client's data and the recipients' data. Next, the client unloads packages one by one onto a scale while the supervisor registers the type of packaging and the goods inside, the CCREG and ABG authorities inspect the cargo, and a color-coded tag is placed in each package with the initials of the recipient. Cargo is loaded in refrigerated or maintenance containers on top of pallets without additional wrapping.

Pictures of this process can be found in annex C.

4.3.2 Consolidation of pallets.

During cargo reception, personnel attempts to structure cargo bundles in pallets that abide to the following guidelines: a maximum height of 1.8 m, cargo is not excessively protruding from the base dimensions of the pallet, and, when possible, bundles should carry all the cargo from one recipient. The organization of packages within the bundle is done by port operator workers that attempt to distribute them by weight, dimensions, and/or the storage specifications depicted in boxes. Pallet bundles are then wrapped in transparent plastic to ease their mobilization in and out of containers.

Pictures of this process can be found in annex D.

4.3.3 Consolidation of containers.

The storage of pallets in containers is completed throughout the 10-day itinerary, except perishable goods which is done the day before shipping. Personnel is instructed to organize cargo within containers by recipient to make the dispatch of cargo easier in the Islands. This instruction is not followed when the recipient delivers goods that may pose a sanitary or safety risk if placed together, which is the case of dangerous goods such as gas and lubricants or cleaning supplies. Daily, port operator workers estimate the space left in each container considering the size and approximate weight of each pallet bundle. This information is passed down to the shipowner, who accepts or rejects cargo based on the available container capacity. The port operator allows each container to be filled up to 80% of its 18-ton capacity, many times piling loose cargo on top of pallet bundles to increase space utilization. These measures are in place not only to improve the probabilities of cargo arriving in good conditions, but because containers undergo land transportation in the Islands, where trailers are only allowed to circulate with a maximum of 50 tons of loading capacity.

This process yields a report called Cargo Manifest, which provides information about the container where the recipients' goods are located, destination of the cargo, and other characteristics such as number of pieces or packages sent and weight. Daily, this report is updated with the containers filled during the day and, once a container is full, this document is placed in the container's door. Additionally, the container is locked with 2 padlocks: one from the port operator and the other from ABG to certify its inspection. When the ship is set to ship, all cargo manifests are consolidated into one file, which is delivered to the shipowner. According to the current legislation for maritime cargo transport to the Islands, the SPTMF and the ports' captaincies require the rendition of this document up to 3 days after the ship sets sail (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016).

Pictures of this process can be found in annex E.

4.3.4 Unloading of cargo in ports of arrival and land transport to container yards.

Given the geographical limitations of the Islands, the ships assigned to the transportation of cargo from the continent are not able to berth directly in the ports (Mazon, 2018). This means that ships berth up to 10km away from the ports and await the arrival of feeder barges, each with a capacity of 4 containers. The ship's crane maneuvers containers on top of each barge, a complex process that is estimated to last between 15 and 25 minutes to complete, depending on climate conditions and the experience of the operator. The barge returns to shore in 12 minutes and another crane maneuvers to place 2 containers per trailer, a process that may take a similar time as the latter. In the case there are empty containers, cranes must maneuver them off the trailers and into the ships, which adds up to 50 minutes per 4 containers. In the case of San Cristobal, ships berth near the bay La Predial and trailers take approximately 9 minutes to cover the 800m distance to the container yard in Puerto Baquerizo Moreno. In the case of Santa Cruz, ships berth in Punta

Carrion north east of the Island and feeder barges transport containers to Itabaca Channel. From this point to the container yard in Puerto Ayora, trailers take between 50 and 75 minutes to cover the approximately 41 km distance. Annexes F and G show the geographical locations of the places referred to in the process.

4.3.5 Dispatch of cargo.

Upon arrival to the container yard, the first few days are the most strenuous for the process, given that recipients are in a hurry to pick up perishable goods. In the case of Santa Cruz, containers are opened by port operator workers who divide the cargo per recipient and approach the waiting room with a list of recipients. They use the cargo manifest in each container and the consolidated cargo manifest to find the cargo belonging to each recipient. Simultaneously, recipients proceed to the shipowner's and the port operator's offices to pay any pending dues for the cargo, scenario that occurs if the dues were not paid in Guayaquil. Additionally, the island of Santa Cruz charges a 5% fee of the freight value for the use of ports, which the recipient must pay before claiming its cargo. Finally, recipients wait their turn in the waiting area until port operator workers call their name to receive the cargo. The recipient carries a document called Packing List where the container number, the type of package and the items per package are detailed, with which it approaches the area designated for cargo dispatch and verifies that all the cargo is present. Finally, the recipient signs a copy of the invoice and takes the cargo. The ship may stay in this island up to 5 days in order to guarantee the return of most of the containers to the continent.

In the case of San Cristobal, the process is similar except for two main differences. One, there are no operators assigned to the deconsolidation of cargo given the low demand of cargo, so the port operator pays recipients to complete this part of the process. They enter the container park with their vehicles and use the Packing List to find the cargo in each container. Second, the island

of San Cristobal does not charge a fee for the use of ports, so the recipient does not have to undergo that process.

In both cases, if the ship is Isla de la Plata, recipients must go to the shipowner's administrative offices outside of the container yard to pay any pending dues, increasing the cycle time of this process.

Pictures of this process can be found in annex H.

4.3.6 Cargo Manifests.

As it was previously explained, it is a requirement that cargo manifests are consolidated every time a ship sets sail. For the present study, files containing cargo manifests from January 2018 to December 2018 were received in order to update data on the levels of cargo transported to the Islands. The table found in annex I characterizes each of the fields found in the files.

5. RESULTS

5.1 Improvement opportunities found in macro processes of the cargo transport system and possible solutions

The following section aims to discuss some of the improvement opportunities that were discovered in each process, which impact directly on the capability of the system to process incoming cargo efficiently. The processes of unloading of cargo in ports of arrival and land transportation to container yards are excluded from this analysis, as they have been reviewed in depth in other studies such as Salazar, 2016.

The potential solutions offered deal with the most relevant restrictions of each process, with the objective to offer the public a robust process that facilitates the processing of cargo to the

Islands. It is worth reminding the reader that any changes to infrastructure must be approved by CCREG and may therefore result inapplicable if denied.

5.1.1 Cargo reception.

As previously mentioned, this process is one of the most relevant in the cargo system and one with the most existing problems. Because of the current nature of the process, the user must go to the shipowner with a written detail of the cargo before such is physically inspected. This is the source of much rework, as there are many incidents where the physical cargo differs from the detail and the user must restart the process in order to correct it. Additionally, when the user visits the shipowner, he is given a turn upon arrival that allows him to go to the warehouse and deliver the cargo. Many times, individuals with less quantity or complexity of cargo will finish the payment process faster and arrive at the warehouse earlier, causing for personnel to receive their cargo regardless of their turn. This causes discomfort among users, who complain that their turn should be respected. Lastly, given the current 10-day cargo reception itinerary, the last day accumulates a high level of demand given that users around the country travel to the container yard to deliver perishables. This causes the formation of long lines outside the location beginning the dawn of this last day, exposing users to safety risks. Cargo is processed from 7:00 am until 5:00 pm by supervisors of the port operator in a visibly slow pace, causing for trucks to accumulate in the yard and many users to wait for extended periods of time to have their cargo received.

Given the weaknesses previously identified, possible solutions to each are proposed below. First, the user should go through physical inspection of the cargo before being charged by the shipowner, and subsequently, by the port operator. In this manner, the final list of goods delivered is assembled and agreed upon by all parties before incurring in administrative procedures. Supervisors from both the port operator and the shipowner should be present to evaluate that the

items sent are charged accordingly. Second, as users arrive to physical inspection, they should receive a turn based on established ranges of quantity and types of cargo, given that these two characteristics are observed to be the most significant in determining the time taken to receive the cargo. This allows for users to be served in an ordered manner, not only in order of arrival, but also based on the nature of the cargo delivered. This should eliminate complains about conflicting turns and alleviate the burden of personnel receiving such complains. Third, due to the high demand that the last day of cargo reception concentrates, the process should be furtherly sealed against surprises. A possibility is to produce online infrastructure that allows users to register their cargo during the days before the 10^{th} day of the itinerary. This would mean that on the beginning of the 10^{th} day, personnel have a detail of all the physical cargo that is supposed to arrive that day, allowing them to plan accordingly in terms of additional personnel and containers. Additionally, this system would allow the certification of users that comply to the detail given online, providing incentives to those that adhere to these practices. This would significantly reduce the pressure of the system on this day particularly and improve the service provided to the community.

5.1.2 Consolidation of pallets.

This process reveals the dependency the system of interest in standardized packaging, which is considered a facilitator of efficient logistics systems as it impacts directly on material-handling equipment and the transportation of goods. Packaging should have some fundamental functions such as: protection, preservation, and convenience. Consequently, packaging is also considered a driver in the costs and general performance of the whole system, which exposes the need to increase its efficiency (Hellstrom & Nilsson, 2011). Within the cargo transport system to the Islands, the user is expected to produce packaging that adheres to the nature of the system, a guideline that is often not followed. Many users send the cargo in regular boxes that do not provide

the functions previously mentioned and put a strain on the consolidation of pallets, as personnel have to practically guess the best accommodation for packages within the pallet. Additionally, the plastic film used to stabilize the cargo in the pallet is applied manually and without a protocol to determine its effectiveness.

A possible solution for the first set of problems would have to be the increase of efforts to encourage users to package the cargo accordingly. A set of guidelines should be structured that direct the user towards safe and sturdy packaging, such as the ones determined by UPS, the world´s largest package delivery company, in their website (UPS, n.d). This would require a joint effort of all the parties involved, public and private, in order to inform the user in a timely manner. Cargo that does not adhere to the guidelines, should be accompanied by a document that releases the port operator of responsibility for the proper arrival of the goods. Secondly, personnel that consolidates pallets should receive training by an authority on the matter on the best practices to handle cargo and organize pallets. Following training, constant evaluation of the pallets produced by personnel should be kept in order to confirm that they have applied the instruction given. This would readily improve this process and all subsequent processes that depend on stable pallets.

5.1.3 Consolidation of containers.

Upon observation of this process, it is visible that personnel loading pallets into containers, in most cases, do not follow guidelines that promote the safety of the cargo. Some lax guidelines are given, such as how much should the container be filled and the instruction of considering putting robust packages at the bottom.

A valid solution for this weakness is provided by the CTU Code[9] chapter 9 and annex 7, which provide guidance on how to plan and execute the packing of pallets and containers. Specifically, instructions on the distribution of cargo and how to secure it within the containers, proves beneficial to the current system (ILO, 2016).

5.1.4 Dispatch of cargo.

One of the main weaknesses of the process is the time the ship must wait in the Islands in order to wait for cargo to be retrieved by recipients and return to the continent with empty containers. Although Panismar personnel explained that the shipowners charge a fee for every day the cargo is not retrieved, the conditions under which such fee is payed are not clear and users appear to not mind if the cargo remains in the yards. Additionally, if users have not payed for the cargo in Guayaquil and is transported in the ship Isla de la Plata, they are forced to visit the offices of Transnave in the center of the town, extending the time it takes for them to recover their goods.

Firstly, an incentive for recipients to claim their cargo promptly should be put in place, such as a discount in their next shipping if they retrieve the cargo within 3 days of arrival of the ship. A comprehensive study should be completed on the costs associative to the idle time of the ship and what percent discount may be profitable to offer. Secondly, Transnave should open an office in the container yards and put in place systems that allow users to complete all transactions within the container yard or, even more so, online. This would reduce the time it takes for users to recover the cargo and, therefore, the idle time of ships.

[9] The CTU Code is a publication by the International Maritime Organization (IMO), the International Labour Organization (ILO) and the United Nations Economic Commission for Europe (UNECE), that aims to provide non mandatory practices for handling and packing shipping containers (ILO, 2016).

5.2 Update of information on the cargo transported to the Islands

When approaching the files received, the main objective was to gather knowledge on the levels and characteristics of the cargo that is sent to the Islands. By obtaining one year's worth of data for the fields mentioned in a previous section, some of the following conclusions were determined. Additionally, a database with the statistics gathered by the MTOP has been used to understand the movement of cargo in terms of tons. Both databases complement each other, as, the MTOP data might provide more accurate figures, the data from the port operator provides the insight required about the different types of cargo and other characteristics of the system.

In first instance, the number of packages sent to each of the Islands is analyzed, determining that during 2018, 21 287 packages were sent to Santa Cruz while 13 646 were sent to San Cristobal. This means that Santa Cruz receives nearly 56% more cargo than San Cristobal, a condition that should be examined to consider concentrating efforts on each Island in a different manner. The island with higher demand has different needs than the island with lesser demand, a circumstance which the cargo transport system should consider to distribute the resources assigned to each in a more efficient manner.

Next, the types of cargo sent to the Islands are observed in order to understand the nature of products entering the Islands. From the databases received, 63 different categories were identified, of which 10 represent 93% of the packages sent. These categories are construction material, non-perishable food items, perishables, beverages, refrigerated items, eggs and appliances. In order to compare this data with the last known statistics for type of cargo sent to the Islands, data recorded in the 2012 study by WildAid, these categories were considered: construction materials, dry food and grains, fresh produce and miscellaneous items. To arrive at these categories, the 63 sub-categories were grouped under each, a task that was fairly

straightforward as the 4 categories are very broad. Annex J displays the change of cargo sent per these categories for the years 2012 and 2018.

The most visible change is observed in the amount of construction materials that are sent to the Islands, which has reduced by 23% in 6 years. According to data from the Galapagos National Park (DPNG), throughout the last 10 years, the compound rate of growth in tourism to the Islands is of 6%, reaching a peak of 275 817 tourists during the year 2018 (Observatorio de Turismo de Galapagos, 2019). There is also a significant growth in hotel infrastructure in this time period, from 106 to 317 businesses, a growth that the DPNG assures exceeded the increase in demand by 2.5% (Observatorio de Turismo de Galapagos, 2019). Nonetheless, in the last 3 years, the number of business has not increased significantly, which is compatible with the reduction in construction materials evidenced in annex J. However, in order to understand the true behavior of the system, more information regarding construction permits and legislation in the Islands should be gathered. Considering the other types of cargo, they have grown in an average of 7.7%, which reflects the recorded growth in different types of touristic business such as travel agencies, restaurants and entertainment establishments. In the 6 years previous to 2012, inclusive, 88 businesses of these characteristics opened while in the 6 years previous to 2019, inclusive, 208 similar businesses opened (Observatorio de Turismo de Galapagos, 2019). This exposes how individuals living in the islands have opened new business perhaps in existing infrastructure, increasing the demand for food supplies and other goods, but not that of construction materials.

Another important discovery is related to the amount of cargo received by certain individuals in the Islands. In 2018, 2 270 different recipients were listed for packages in the data base of the port operator. Even so, 140 of these represent 80% of the packages sent to the Islands, less than 7% of the total recipients. A similar statistic can be deduced from the number of shippers,

of which 7.2% represent the 80% of packages sent. This means that the system deals with the same recipients and shippers, a discovery that was corroborated by authorities during the visits to the container yards. This provides an immense opportunity to generate programs to certify certain recipients and shippers as trusted suppliers of the system. According to the Institute for Supply Management, maintaining a constant evaluation and certification of suppliers allows an improved visibility of suppliers' performance, improved communication that results in the mitigation of hidden wastes and costs, and the alignment of suppliers' practices to the objectives of the business (Gordon, 2006). Treating familiar recipients and shippers as suppliers might improve the efficiency of problematic logistic activities in the cargo transport system.

Next, some important parameters were determined using the databases provided. First, the demand of the islands in terms of containers per cargo type. It was observed that each container may carry different cargo types but there are 3 types of cargo that are grouped in the same containers: refrigerated cargo, fresh produce and others. The 63 categories previously identified were grouped into these 3 categories, which may represent to a certain degree the current conditions in which cargo is handled in terms of costs. It is worth noting that the shipowners have additional types of containers and the port operator may have additional categories for dividing cargo between containers, but this information was not available at the time the study was completed. Data regarding the parameters determined can be found in the table in annex K.

Next, the data regarding the number of trips to the Islands was analyzed, in order to understand if the 12-day itineraries provided by the MTOP are usually followed. Between January and July of 2018, the average time between trips is of 13.5 days with a minimum of 7 days and a maximum of 18 days. There is no data for the month of august, so between September and December of 2018, the average time between trip was of 14.7 days with a minimum of 13 days

and a maximum of 19 days. According to MTOP, the established itineraries may vary with 3 days due to climate factors, loading/unloading operations, cleaning and fumigation of ships and containers, and the avoidance of Monday as a day for ships to set sail (SPTMF, 2019). This data further puts in evidence the inability for the system to supply demand with the required frequency and return to mainland in the expected time frame.

Lastly, the utilization of ship capacity was determined for the year 2019 in terms of tons of weight. For this analysis, another reliable source was used to understand the amount in tons of the cargo sent to the Islands, as the databases received from the port operator had many null values in this field, which prevented a comprehensive conclusion. According to the cargo statistics provided by the MTOP for the year 2018, 69 346 tons of cargo were sent to the Islands, a 14% growth from the levels recorded in 2012 (Brewington et al, 2012). Therefore, the utilization of the 2 ships that are currently active in the system for containerized cargo was in average 97%. Additionally, within the first 7 months of 2019, the data reveals that the utilization of the same ships dropped to an average of 92%. This utilization rates are highly elevated, compared to the utilization rates used in the 2012 WildAid study, where a 75% utilization rate was estimated (Brewington et al, 2012). This reveals that the system may be reaching its limit, given the significant rise in the observed utilization and peak in cargo sent during the year 2018. It is worth noting that there is no data regarding the amount of cargo that is rejected from the maritime cargo system or that should be sent through this system but is otherwise sent through air cargo services. This hole in the data could reveal the actual extent to which the system needs to grow in order to accommodate the needs of the Islands.

5.3 Exploration of possible ship routing to optimize the supply of the demand

After determining the current state of the Islands, it is noticeable that the cargo needs of each of the Islands is distinct and may therefore require a different adaptation of the cargo transport system. The model used to evaluate this possibility is known as the Heterogeneous Vehicle Routing Problem with Vehicle Dependent Routing Costs. In the literary review it was observed that this type of problem was widely used to route ships and cargo without including time concerns such as port visiting frequency or idle times in ports, matters that have not been studied in detail in the context of the Islands. Therefore, this sort of problem could be used to obtain an introductory understanding of the capacity of the system by determining if the fleet assigned to the system is routing cargo to the Islands in the most cost-effective way. To this aim, a static demand for a 14-day service and fleet costs that exclude capacity dependent parameters, such as operational and capital cost, are considered. Consequently, this model deals with the strategic decision of determining appropriate fleet size and mix, using ships that may be available to the system as the types of ships available.

In this problem, the objective is to determine the route each type of ship must follow in order to supply the demand of both Islands, while minimizing the fleet cost of the service. This will evidence if the current routing of the cargo is the most efficient or if an alternative will continue to serve the islands at lower fleet costs for the shipowners.

5.3.1 Mathematical Formulation.

$$Minimize \ \sum_{k}^{M} \sum_{i \neq j}^{V'} c_{ij}^{k} \, x_{ij}^{k} \qquad (1)$$

$$\sum_k^M \sum_i^V x_{ij}^k = 1\,, \quad \forall\, j \in V' \tag{2}$$

$$\sum_i^V x_{ip}^k - \sum_{i \neq j}^V x_{pj}^k = 0, \quad \forall\, p \in V', \forall\, k \in M \tag{3}$$

$$\sum_k^{V'} x_{ij}^k \leq m_k, \quad \forall k \in M \tag{4}$$

$$\sum_i^V f_{ij} - \sum_i^V f_{ji} = d_j\,, \quad \forall\, j \in V' \tag{5}$$

$$d_j x_{ij}^k \leq f_{ij} \leq (Q_k - d_i) x_{ij}^k, \quad \forall\, j \in V, i \neq j, \forall\, k \in M \tag{6}$$

$$f_{ij} \geq 0, \forall\, i, j \in V, i \neq j \tag{7}$$

$$x_{ij}^k \in \{0,1\}, \forall i, j \in V, i \neq j, \forall k \in M \tag{8}$$

In the formulation above, constraint (2) restricts ships to visit each port one time, while constraint (3) requires the ship to leave a port after visiting it. Constraint (4) restricts the number of ships available for all types of ships, which given the context of the Islands, is set to 1. Constraint (5) determines that the difference between the quantity of goods a ship carries when entering and exiting a port must be equal to the demand at that given port. Constraint (6) prevents the flow of cargo between ports to exceed the capacity of the ship. Constraints (7) and (8) define the integer and binary variables respectively, where the first determines the quantity of containers moving between ports and the latter, the ship that moves cargo between the given ports. Finally, $i = 0$ is considered as the port of Guayaquil.

The problem has been determined in the context of optimizing the fleet cost of serving the demand every 14 days, which is the current average frequency at which ports are served in Galapagos. Therefore, for each port, the container demand for that time frame has been considered, as well as the total capacity of each type of ship. The transportation cost is different for every type of ship, parameter deduced from databases obtained from the port operator of the system. In order to implement the model, the software AMPL was used with the CPLEX 12.6.3 solver. Given the limited number of nodes and types of ships, the time required to achieve a solution did not precise the use of heuristics.

Below, the description of each of the scenarios studied in order to assess the capacity of the system to serve the Islands' demand. The intention of each scenario is to evaluate the impact of a change in demand and availability of ships on the amount of cargo the system is able to deliver to the Islands and the associated fleet cost. In order to structure the scenarios, some assumptions have been considered. First, the ship's capacity utilization is 97.5%, as a 100% utilization is considered not viable (Adland,Jia & Strandenes, 2016). Consequently, whenever the cargo exceeds this value, the exceeding cargo should be left in the warehouse at the container yard and be sent in the next scheduled shipping, according to the legal guidelines of the MTOP (Normativa Transporte Marítimo de Carga desde Ecuador hacia Galapagos of 2016). Additionally, demands referred to in each scenario correspond to the demand of 14 days of the Islands for the year 2018. As well, as previously noted, the port operator attempts to fill each container up to 80% of its capacity, restriction that is also considered in each scenario. Annex M provides a summary of each scenario considered.

It is worth clarifying that the mathematical formulation only deals with the allocation of containerized cargo, not the loose cargo that is also added to the ships during each service. The

scenarios below take the optimal solution produced by the model and evaluate the impact on capacity utilization of adding demand for loose cargo in terms of tons. The current data available does not record the demand of loose cargo per Island, only an aggregated value, which prevented the consideration of this factor in the model.

5.3.2 Results for scenario 1.

Part A of the first scenario considers the average demand for 14 days of the islands for the year 2018 and the types of ships that are currently in service: ship Isla de la Plata with a capacity of 226 containers and ship Fusion II with 373 containers. With a final cost of $36 137, to serve the demand of 129 and 58 containers for Santa Cruz and San Cristobal respectively, only the Fusion II ship is necessary. In terms of number of containers, the utilization of the ship is of 50%. In terms of weight, the average demand for loose cargo was also considered, which is approximately 116 tons. This means that the utilization of the ship is of 80%.

Part B of this scenario considers the current conditions of the system where one ship serves the islands once a month, meaning that the other ship completes the second trip of the month. In this case, Fusion II is eliminated from the model and Isla de la Plata is assigned to the route with a final cost of $42 324. In terms of containers, the utilization of the ship is 83%. In terms of weight, the utilization of the ship is 140%, which means that at least 42.5% of the cargo would have to return to the warehouse before setting sail.

5.3.3 Results for scenario 2.

The second scenario considers the current compound rate of growth of tourists' arrivals to the Islands of 6% as a direct predictor of growth of cargo levels for each Island. Such increase is applied to the maximum demand recorded for both Islands during the year 2018, in order to put the system to the test. Additionally, a ship under the name Baltic with 146 containers of capacity

is added to the model. According to MTOP statistics for the year 2018, this ship used to serve the Islands but was taken out of the fleet until it could provide adequate safety measures. With a final cost of $36 137, to serve the demand of 183 and 109 containers for Santa Cruz and San Cristobal respectively, only the Fusion II ship continues to be necessary. In terms of number of containers, the utilization of the ship is of 78%. In terms of weight, considering the previous assumptions about additional weight, the utilization of the ship is of 123%. This means that at least 31% of the cargo would have to return to the warehouse before setting sail.

5.3.4 Results for scenario 3.

The third scenario considers the possibility that the ship Fusion II requires maintenance and is unable to complete trips for a given month. Demand and the remaining types of ships are kept at the levels of scenario 2. With a cost of $60 874, to serve the demand of 183 and 109 containers for Santa Cruz and San Cristobal respectively, Isla de la Plata is routed to Santa Cruz and Baltic to San Cristobal. In terms of containers, the ships have an average utilization rate of 78%. In terms of weight, one additional assumption has been made, that the ship Baltic has a carrying capacity proportional to the ship Isla de la Plata considering its number of containers. This means that the average utilization of the ships is 79%.

5.3.5 Results for scenario 4.

This scenario considers the growth of population of the Islands projected to 2040 and 2050 in order to observe the growth of cargo demand for Santa Cruz and San Cristobal. According to the 2015 census of the Islands, the annual rate of growth for each of the Islands is 2.4% for Santa Cruz and 0.8% for Santa Cristobal (INEC, 2015). Assuming that the rate of annual population growth remains the same, the population for 2018, 2040 and 2050 is calculated. Next, it is also assumed that there is a direct relationship between the levels of cargo sent to the Islands and the

size of the population. Given that data for levels of cargo in 2015 were not available, using the maximum levels of cargo recorded for the year 2018, the projected cargo levels for Santa Cruz and San Cristobal in 2040 and 2050 are also calculated. Maximum recorded cargo demand is used in order to evaluate the system under pressure. Data regarding the population and cargo estimates is summarized in the table found in annex L.

Firstly, in the case of projected growth for the year 2040, with a cost of $74 830, to serve the demand of 206 and 174 containers for Santa Cruz and San Cristobal respectively, Fusion II is routed to Santa Cruz and Isla de la Plata to San Cristobal. In terms of containers, the ships have an average utilization rate of 66%. In terms of weight, which means that at least 4% of cargo has to return to warehouse before shipping. In terms of weight, the ships have an average utilization rate of 104%. This means that at least 6% of the cargo would have to return to the warehouse before setting sail.

Lastly, in the case of projected growth for the year 2050, with a cost of $74 830, the same ship routing as the 2040 scenario is required to fulfill demand. In this case, although the average utilization in terms of containers remains at 79%, the utilization rate for Isla de la Plata is at 97%. In terms of weight, the average utilization is at 121%, which means that at least 20% of the cargo would have to return to the warehouse before setting sail.

6. DISCUSSION

6.1 Characteristics of the system: macro-processes and levels of cargo

Returning to the questions established at the beginning of the study, the different answers to each are now discussed. The processes individuals must undergo in order to deliver cargo to the Islands was understood in a general manner, determining that there exist 7 processes through which

cargo arrives to the Islands. Within these processes, the weaknesses of 4 of them were particularly analyzed for improvements that could be applied to the logistic process in order to increase overall efficiency of the system. In the case of cargo reception, it is a process that should undergo serious changes to increase its efficiency. Physical inspection should become the first point of contact with the client, turns should be given upon arrival of the client according to ranges of quantity and types of cargo, and an online interface for users delivering cargo on the 10th day of the itinerary should be implemented. In the case of consolidation of pallets and containers, training with the CTU Code would be of great benefit to improve the stability of pallets and the distribution of cargo within containers. Additionally, the port operator should develop guidelines for the user to follow in order to produce valid packaging, which should be actively promoted by all the authorities involved. Lastly, regarding the dispatch of cargo in the Islands, an incentive should be developed to encourage recipients to recover their cargo as soon as possible. This could be in the form of a percent discount given in the next cargo shipping. As well, Transnave should set up an office in the container yard and structure a system that allows users to complete all transactions without moving beyond the yard.

Next, the questions regarding the parameters under which the system functions have been determined to a certain extent. In the case of itineraries, routes and ships, this was fully understood during the visits to the container yards, where the role of the MTOP in developing routes and itineraries was understood. The ships are also authorized for service by this entity, but they are owned by independent shipowners. Currently, there are two serving the cargo transport system, each with a ship that rotates visiting the Islands approximately every 14 days. The update on data regarding the movement of cargo was determined, partly from the cargo manifests received from the port operator and partly from statistics of the MTOP. The cargo could still be widely

understood in 4 main categories: construction materials, dry food and grain, fresh produce, and other miscellaneous merchandise. It was discovered that between 2012 and 2018, the first category had reduced from a 60% to a 37%, and the rest of categories had increased an average of 7.7%. Analyzing the growth of tourism and businesses during the same time, it was understood that the growth of infrastructure had decelerated while businesses continued to open in existing infrastructure. Nevertheless, the peak in tourism of 2018 does reflect upon the growth of the other categories, which respond to a need of feeding and entertaining both tourists and inhabitants.

Another relevant insight was regarding the familiar recipients and shippers in the cargo transport system, both of which represent 80% of the packages sent to the Islands. This provides another opportunity for improvement of the logistic processes within the system, as evaluating their performance as suppliers could improve their compliance to packaging guidelines and newly modified processes. Other important parameters were determined such as the approximate number of containers distributed amongst three different types of cargo, the average time between trips to the islands and the utilization of ship capacity. The first allows for another perspective of the levels of cargo as it characterizes the magnitude of demand in terms of a standard cargo transport unit, which could be used to understand the costs incurred by shipowners. The second revealed an average of 14 days in between trips to the Islands, while the latter exposed a growth of 14% in the tons of cargo sent in comparison to 2012 and an average ship capacity utilization of 97% during 2018 and 92% during the first 7 months of 2019.

6.2 Possible insights from mathematical formulation scenarios

The first scenario exposes the current capacity of the system, which is highly dependent on the availability of the ship Fusion II due to its high container and overall weight capacity. The total transportation cost for the route increases 17% when using the ship Isla de Plata, and so does the

risk of having to leave cargo behind for a subsequent shipping, which in the case reaches a maximum of 31%. This finding is surprising as this means that every month, potentially, this amount of cargo is most likely rejected from users or stored in the warehouse for at least 15 days.

The second scenario attempts to consider an increase of container demand due to an increase of tourist flow to the Islands. Although the transportation cost remains the same as part A of scenario 1, the percent of cargo exceeding the ship's capacity is 21%, which means the demand is not fully met by this ship. In order to fulfill this demand, an additional ship should be assigned to carry the approximately 860 tons, meaning that two ships should serve the Islands every 14 days instead of one.

The third scenario considers the possibility that Fusion II is not available, in which case the other two ships should supply the demand for the Islands. The result is a final transportation cost of $60 874, nearly 70% higher than the current situation. In this case there is no cargo leftover in the warehouse.

The fourth scenario allows a view of the future of the Islands, where the population might grow at the current annual rate and, proportionally, so as the cargo demand. In this case, both Fusion II and Isla de la Plata would have to supply the demand of the Islands, resulting in a final transport cost of $74 830. Even when the cost has doubled, there is still approximately 367 tons of cargo that would have to be rejected or assigned a third vessel. An even more dramatic situation is evidenced in the 2050 projection, where nearly 1314 tons of cargo are not delivered to the Islands. It is clear that, if the cargo demand reaches the projected levels, in order to fulfill the 14 days of demand for Santa Cruz and San Cristobal, 3 ships would need to become part of the fleet.

The scenarios analyzed clearly evidence the limitations faced by the maritime cargo transport system. First, the level of service it can provide to the Islands is highly dependent on the

availability of the ship Fusion II. The system clearly favors cost efficiency over fulfilling the demand of the Islands, given that the current practice of alternating between Fusion II and Isla de la Plata may allow two shipowners to earn profit from the system instead of one, but it also causes a significant amount of cargo to wait an additional 14 days to be shipped. Second, the scenarios also reveal plenty of hidden costs resulting from the inefficiencies of the system. The cost of warehouse space for the cargo that is unable to be shipped or the loss of revenue when cargo must be rejected due to lack of capacity is not considered or monitored as an indicator. Also, this situation is potentially a direct cause for the rise of prices in the Islands, which may lead to scarcity of products in the Islands or a higher cost of transport when the user must opt to send the cargo through cargo airlines. Third, the model also reveals the limited size of the vessel market that the system has access to, given that there are only 2 ships that are currently authorized to work for the system and an additional unit that has yet to be adequate for operation. This situation definitely restricts shipowners from being able to provide more vessels in order to supply the demand of the Islands.

7. LIMITATIONS

There are several limitations that must be considered in order to assess the accuracy of the study completed. Firstly, time was a great restriction as it prevented the interaction with the pertaining authorities in order to corroborate data validity. Additionally, there were some conflicts between the data provided by the port authority and the MTOP, mainly due to a lack of data base organization and procedures regarding data analytics. This restricted the level of insight available regarding the tons of cargo per type of cargo, an essential data to further comprehend the system. Secondly, cost parameters used in the model may not as precise as intended, in order to protect the confidentiality of the port operator. Nevertheless, the data kept the proportions of these values

intact and therefore allow for adequate conclusions. Thirdly, due to the time restriction, the solutions proposed were not presented to the port operator at the time of the study. This prevents any sort of feedback in order to assess the feasibility of the ideas and whether there exist additional obstacles to consider. Lastly, the model formulated to present several optimizations scenarios fails to consider hidden costs regarding the handling of different types of cargo. It is also restricted by the data available, which impeded the consideration of loose cargo demand on the model itself. Regardless, the solutions analyzed provide an appropriate baseline for further studies to introduce restrictions to more effectively represent the reality of the system.

8. CONCLUSIONS

Having completed the study, it is worth reviewing some of the most relevant findings achieved. After concluding visits to the container yards in Guayaquil, Santa Cruz and San Cristobal, the study has attained a broad understanding of the 7 macro processes cargo must undergo to arrive to the Islands. Of these, 4 were further analyzed to discover the weaknesses that may directly affect the ability of the system to efficiently provide for the community. Regarding the actualization of data regarding cargo types and the newly discovered data regarding number of containers per cargo type and packages per recipients and shippers, it is recognizable that the Islands have modified their needs since 2012. In particular, given that the demand for construction materials has reduced substantially, while food and other items continue to increase. Finally, after having observed the different scenarios for the routing of ships to supply for the demand of the Islands, it is clear that the current system is under abundant pressure to sustain the Islands while facing elevated transport costs. The heavy reliance on the ship with most capacity is a great vulnerability of the system and should be mitigated to avoid reducing the level of service to the Islands. Conclusively, if the demand continues to increase proportional to the population growth,

then the system will undoubtedly have to add another ship to the Islands in order to fulfill the 14-day demand of Santa Cruz and San Cristobal.

Future research in this field is highly promising now that the present status of the maritime cargo transport system has been comprehensively observed. Looking at the standpoint of the internal processes that take place in the ports, there is still work to be done in recording the duration of each in order to understand the impact of the restrictions that exist in each. Another aspect for analysis is the standardization of the process for retrieving the data that translates into the cargo manifests. An organized procedure, descriptive fields and established categories would allow a continuous update of the movement of cargo to the Islands. This information proves valuable both to shipowners and the port operator, as well as public entities such as CGREG and MTOP. From the standpoint of the mathematical model, there is room to study the frequency of the services that should be implemented to favor both the supply of demand and the costs structures of shipowners. Additionally, considering the costs and demands per type of cargo as factors in the routing exercise, could produce a more extensive discernment of the limitations of the system.

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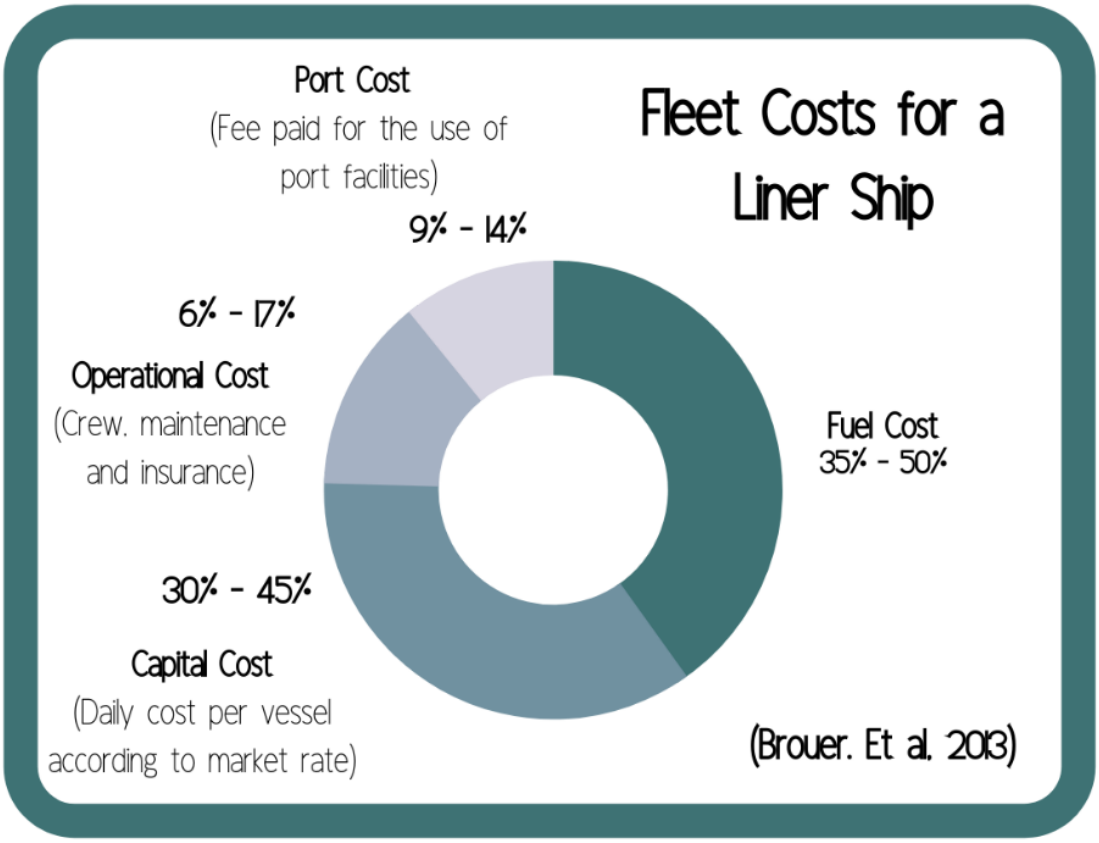
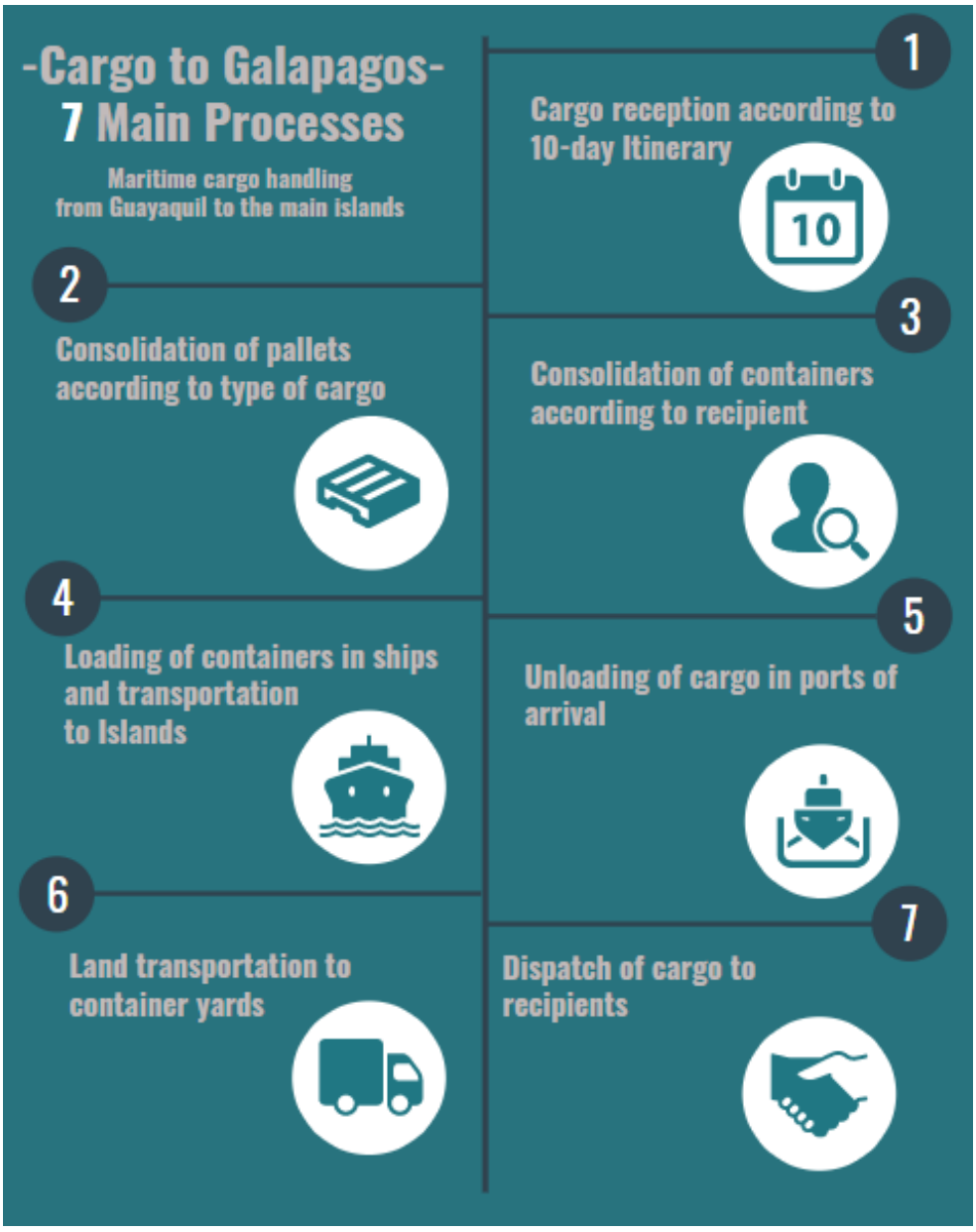
ANNEX A: FLEET COSTS FOR A LINER SHIP



ANNEX B: MAIN MACROPROCESSES FOR THE TRANSPORTATION OF MARITIME CARGO TO THE ISLANDS



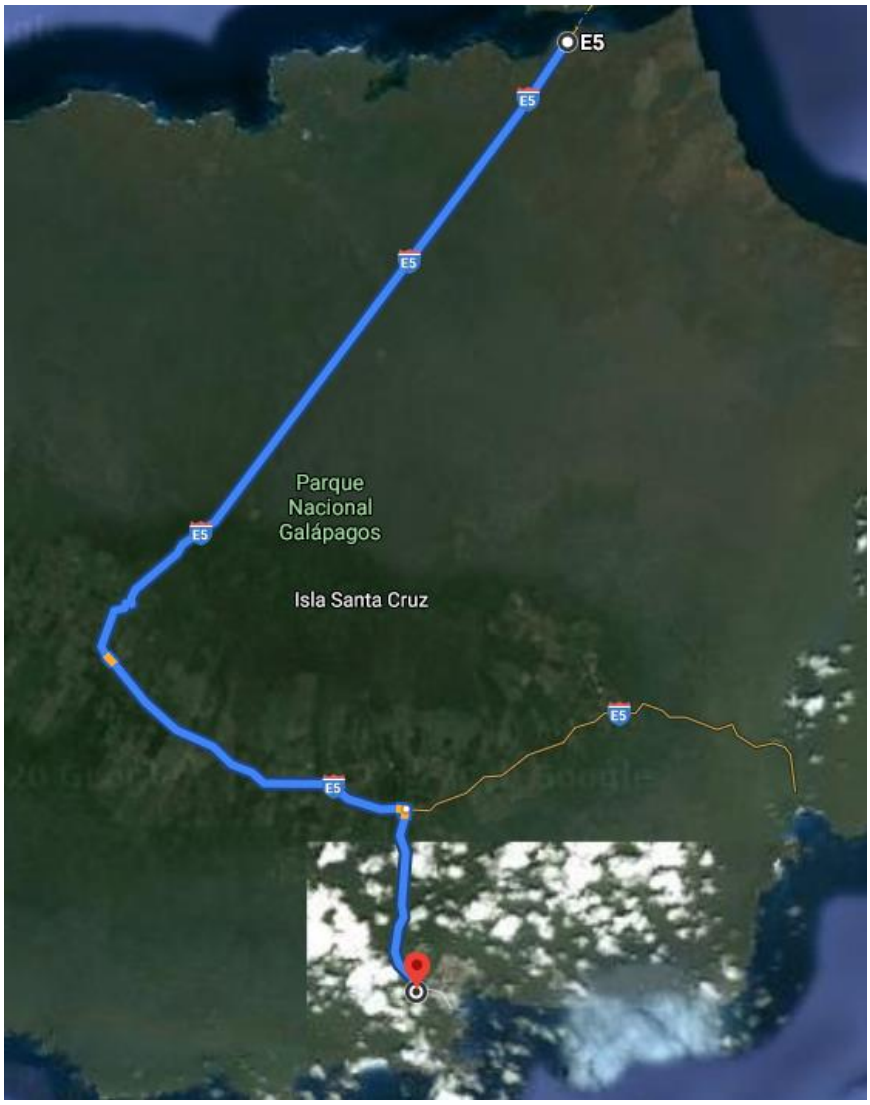
ANNEX C: CARGO RECEPTION AT THE WAREHOUSE IN THE CONTAINER YARD IN GUAYAQUIL, FEBRUARY 2020

ANNEX D: CONSOLIDATION OF PALLETS AT THE WAREHOUSE IN THE CONTAINER YARD IN GUAYAQUIL, FEBRUARY 2020

ANNEX E: CONSOLIDATION OF CONTAINERS AT THE WAREHOUSE IN THE CONTAINER YARD IN GUAYAQUIL, FEBRUARY 2020

ANNEX F: JOURNEY FROM BAY LA PREDIAL TO THE CONTAINER YARD IN PUERTO BAQUERIZO MORENO, SAN CRISTOBAL

ANNEX G: JOURNEY FROM ITABACA CHANNEL TO THE CONTAINER YARD IN PUERTO AYORA, SANTA CRUZ



ANNEX H: CONTAINER YARD IN PUERTO AYORA, SANTA CRUZ, FEBRUARY 2020

ANNEX I: FIELD DESCRIPTION FOR CARGO MANIFESTS FILES, JANUARY-DECEMBER 2018

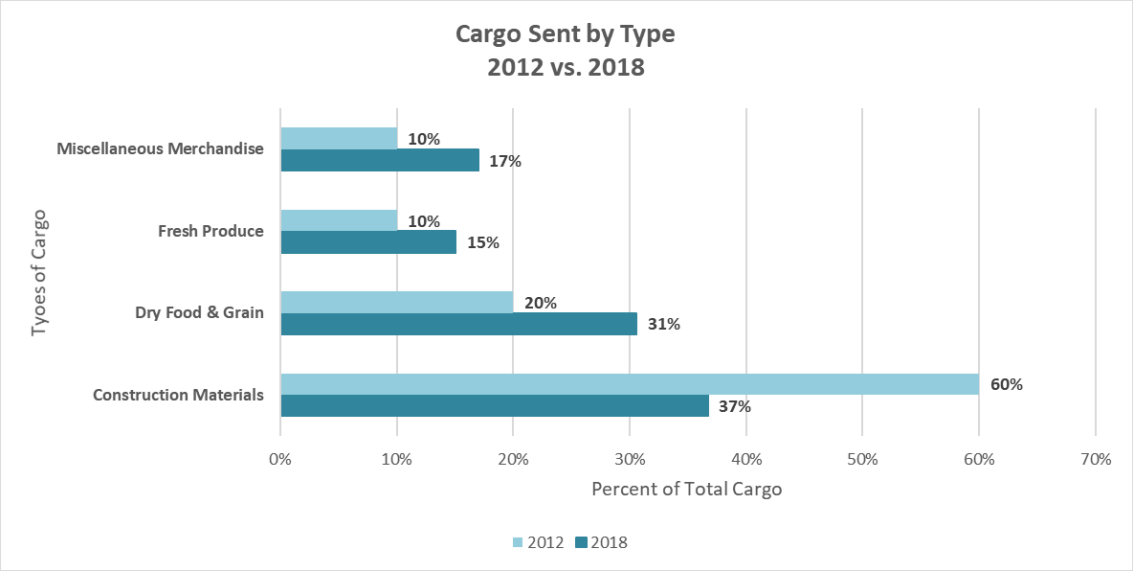
Field	**Description**	**Possible Values**
Container No.	Alphanumeric code given to each container. Identifies shipowner and number.	Many possible values. Ex: BBTU2255836 CARGA SUELTA SC FUSION 2
Date Cargo Manifest	Date cargo manifest completed.	Dates
Ship Code	Ship code identifying each ship.	FX (Fusion) TIP (Isla de la Plata) FX2 (Fusion II) BAL (Baltic Betina) MN (Manantial) PNT (Paola)
Dispatch Status	Identifies whether a container has been dispatched to the ship.	E G T * In this case, the meaning of each letter was not disclosed by the port operator

Origin	Port of origin	GYE (Port of Guayaquil)
Destination	Port of destination	AYO (Port Ayora, Santa Cruz Island) BAQ (Port Baquerizo Moreno, San Cristobal Island)
Date Container Completed	Date container completed and assigned to ship.	Dates
Weight of cargo	Weight of cargo in pounds	Magnitude in pounds
No. of pieces	Number of separate bundles of a specific client assigned to a container.	Quantity
Cargo Type	Categories assigned to cargo.	Approximately 63 different categories
HBL No.	Number corresponding to the House Bill of Lading[10] issued	Numeric code

[10] House Bill of Lading: Document issued by an Ocean Transport Intermediary (OTI) or non-vessel operating company (NVOCC) to acknowledge the receipt of goods that are to be shipped (Pappas, 2013)

	for that cargo	
Recipient	Person in the islands who is responsible for receiving the cargo	Full name of person or company
Shipper	Person who delivers goods to be shipped in representation of the recipient	Full name of person or company
Registry No.	Code to identify goods shipped under the same document to the same recipient according to ship.	Alphanumeric code
Goods	Sub type of cargo under general categories	Over 63 categories
Handling $	Cost of handling goods within port operator facilities and loading/unloading operations	Amount in dollars
Tariff $	Fee charged according to the destination of the cargo	San Cristobal or Santa Cruz: 35% of the price charged by the shipowner
Transport $	Cost of transporting goods	Amount in dollars

ANNEX J: PERCENT OF TOTAL CARGO SENT TO SANTA CRUZ AND SAN CRISTOBAL BY TYPE OF CARGO IN 2012 AND 2018



ANNEX K: NUMBER OF CONTAINERS PER CARGO TYPE HEADED TO SANTA CRUZ AND SAN CRISTOBAL, 2018

	Refrigerated Goods	Fresh Produce	Others	Total Cnt. Per Island
Santa Cruz	43	591	2246	2880
San Cristobal	20	245	980	1245
Total Cnt. per Cargo Type	63	836	3226	

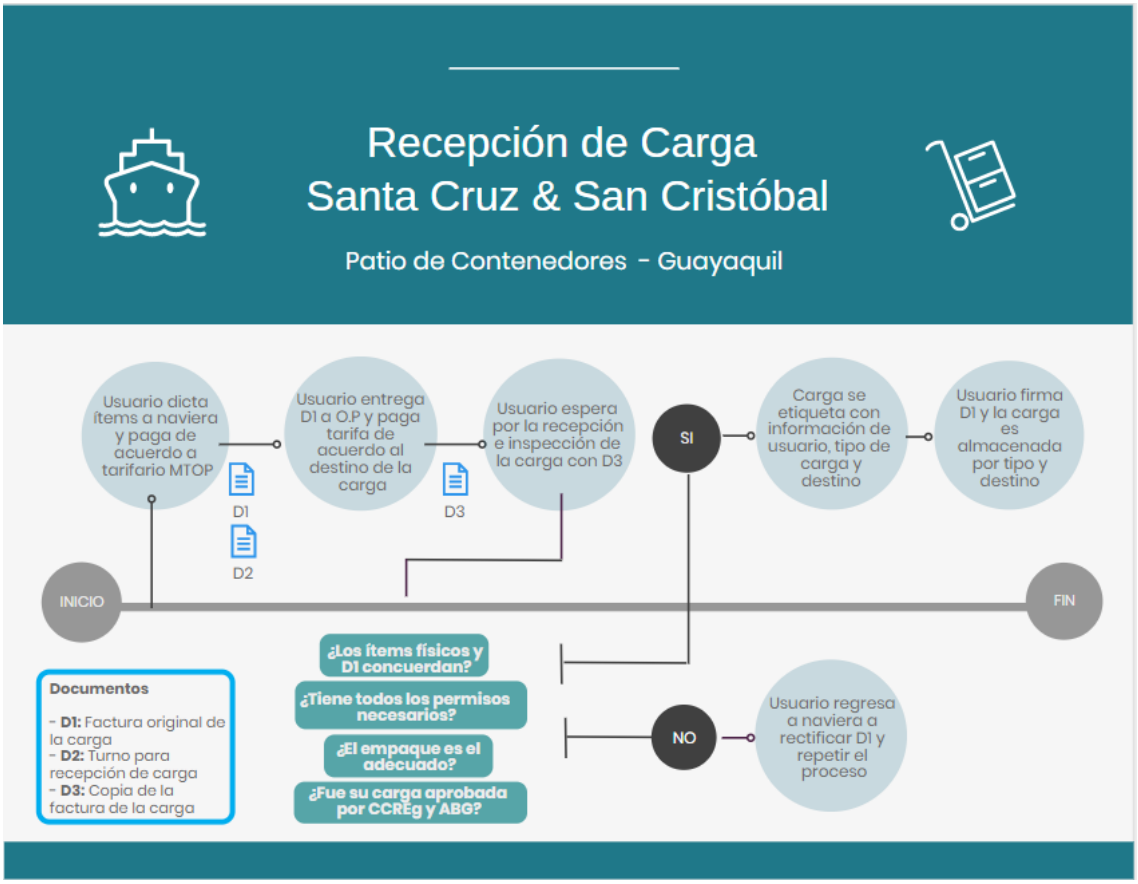
ANNEX L: POPULATION AND CARGO ESTIMATES FOR 2018, 2040 AND 2050

	Population 2015 Census	Estimated Population Year 2018	Estimated Population Year 2040	Estimated Population Year 2050	Estimated Container Demand 2040	Estimated Tons of Loose Cargo Demand 2040	Estimated Container Demand 2050	Estimated Tons of Loose Cargo 2050
Santa Cruz	15701	16081	19162	20751	206	257	223	297
San Cristobal	7199	7730	13025	16511	174	257	220	297

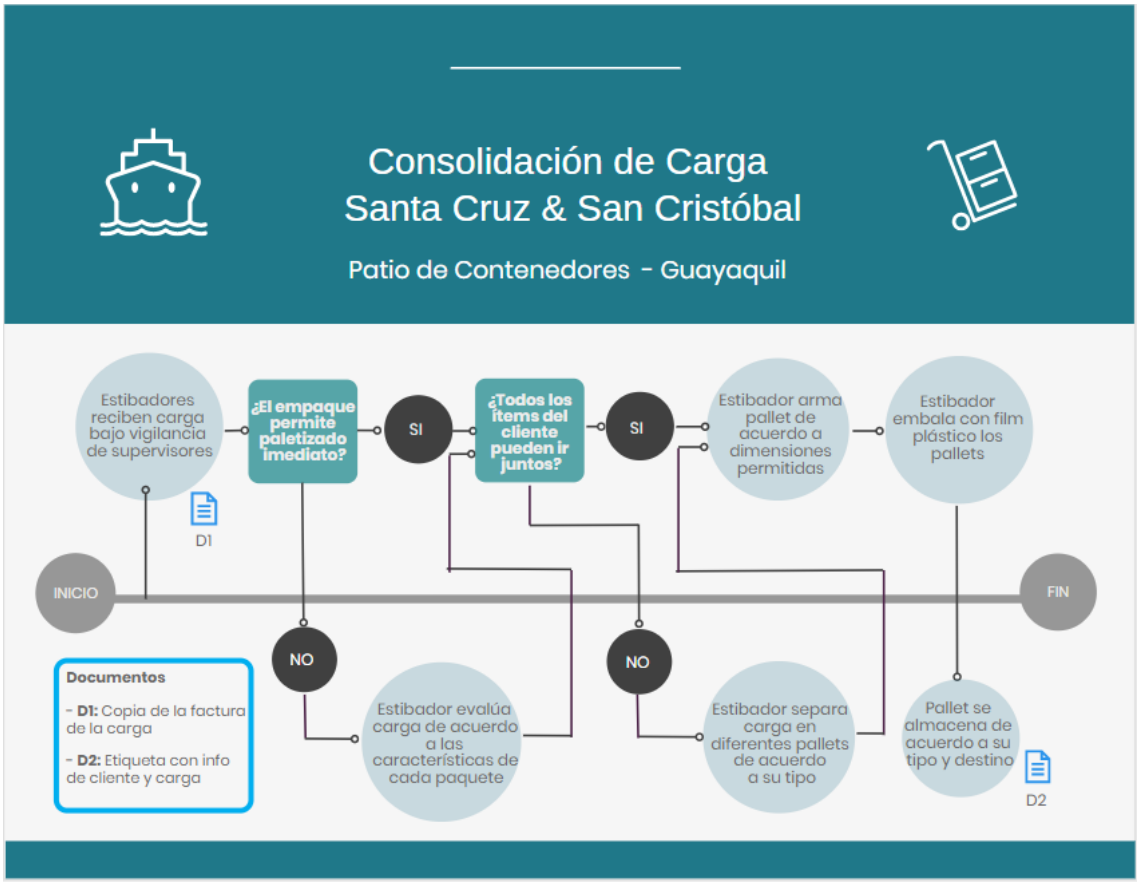
ANNEX M: SUMMARY OF SCENARIOS OF MODEL IMPLEMENTATION

	Container Demand Santa Cruz	Container Demand San Cristobal	Ships Available	Ships Used	Tons of Loose Cargo	Total Transportation Cost	Average Ship Container Utilization	Average Ship Weight Utilization	Percent of Cargo Left in Warehouse
Scenario 1: A	129	58	2	1	116	$ 36,137	50%	80%	-
Scenario 1: B	129	58	1	1	116	$ 42,324	83%	140%	31%
Scenario 2	183	109	3	1	116	$ 36,137	78%	123%	21%
Scenario 3	183	109	2	2	116	$ 60,874	78%	79%	-
Scenario 4 : 2040	206	174	3	2	257	$ 74,830	66%	104%	6%
Scenario 4 : 2050	223	220	3	2	297	$ 74,830	79%	121%	20%

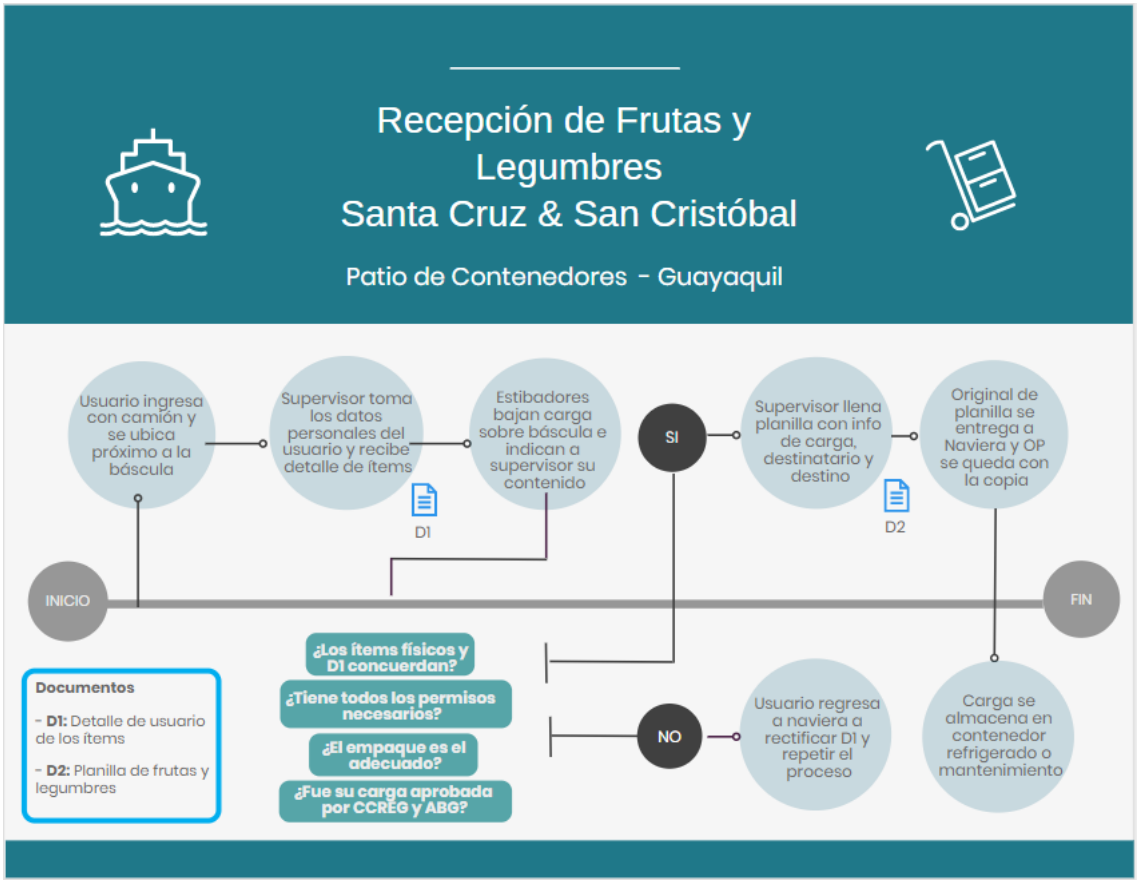
ANNEX N: DIAGRAM OF THE PROCESS OF CARGO RECEPTION



ANNEX O: DIAGRAM OF THE PROCESS OF CARGO CONSOLIDATION



ANNEX P: DIAGRAM OF THE PROCESS OF RECEPTION OF FRESH PRODUCE



ANNEX Q: DIAGRAM OF THE PROCESS OF UNLOADING CARGO IN SANTA CRUZ