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Direct Port Call System Vs. Hub and Spoke System: The West and Central Africa Region

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Abstract

This paper discusses the most profitable way for government and especially shipping lines for serving the WCA region from Europe and Asia using Hub & Spoke System or Direct Port Calls System. Three methods are used: Port aggregation, ship routing and cargo allocation. The aggregation is done using a qualitative analysis and location problem. While for the ship routing and cargo allocation are determined using model simulations with Excel solver to obtain the most profitable routes for the two systems. A comparison is done to determine the best way to serve the WCA region between the two systems. The results show that the highest profit is obtained through Direct Port Calls System while serving the WCA region. It is concluded that the best way for shipping lines is continue to serve through Direct Port Calls System.

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List of Abbreviations

AMSSA	African Maritime Safety and Security Agency
BAL	Bolloré Africa Logistics
CMA-CGM	Compagnie Maritime d'Affrètement-Compagnie Générale Maritime
DCPS	Direct Port Calls System
DPW	Dubai Port World
EPA	East and Pacific Asia
GDP	Gross Domestic Product
GPA	Gambia Ports Authority
GPHA	Ghana Ports and Harbors

HSS	Hub & Spoke System
LCT	Lomé Container Terminal
LPA	Lagos Port Authority
MLTC	Maritime Logistics & Trade Consulting
MSC	Mediterranean Shipping Company
NM	Nautical Miles
O/D	Origin/Demand
RORO	Roll-On/Roll-Off
STSC	Ship to Shore Crane
TEU	Twenty-foot Equivalent Unit
TRT	Turn Round Time
TSP	Travelling Salesman Problem
UN	United Nations
US	United States
WA	West Africa
WCA	West and Central Africa
WITS	World Integrated Trade Solution
WTO	World Trade Organisation

Chapter 1 Introduction

1.1 Topic introduction and relevance:

Since many years' containerization did bring a number of challenges to all actors in the maritime industry, and changed the way ports are served. Thus, pushed shipping lines and terminal operators to select appropriate port of calls in order to ensure the health and continuity of certain shipping routes. Furthermore, for some regions they developed global networks based on Hub & Spoke ports and invested in big ships, machinery and infrastructure to hoist those ships and serve those areas in an efficient and effective way. Thus, resulted to reduce the number of vessels calling in some ports and that in order to achieve economies of scale and reduce operational costs.

For many years shipping lines faced many problems and challenges while serving the West and Central African (WCA) market, due to a lack of port infrastructures and equipment's, which made freight rates and handling costs too expensive, for both shipping lines and consumers. Small feeder vessels served the African market for many years with a capacity ranging from 900 to 2,500 TEUs. Thus, due to geographical restrictions, canal access, small draught and inefficiency of handling equipment's in those ports.

Figure 1: The West and Central Africa Region

Source: (AMSSA, 2017)

To solve this problem, in the last decade due to globalisation, and economic growth in the WCA region; terminal operators and governments decided to invest huge amounts of money to develop ports and terminal infrastructures in many countries such as: Nigeria, Ghana, Ivory Coast, Cameroun, Benin, and Togo. Thus, to increase the competitiveness and attractiveness of those countries to foreign investors, reduce costs, and increase profit while reaching economies of scale for shipping lines.

1.2 Research Question Introduction:

This paper addresses the problems faced in the WCA region, especially for governments and big terminal operators (APM terminals, Dubai Port World (DWP), Bolloré Group) and shipping liners like (MSC, CMA CGM, COSCO, Maersk line) that are investing in various ports in the WCA region for a race of a transhipment hub status. This may increase the attractiveness and competitiveness of these ports but a huge problem may result in the future, which is overcapacity. Table 1 below gives an insight of the future ports, extensions of existing one, and their estimated capacity.

Table 1: Key Capacity Expansion Projects in WCA Region.

Project	Capacity, TEU	Water depth, m	Quay length, m	Terminal operator	Shipping line affiliation
Dakar	1.6 million	15.0m	1,200m	DP World	None
Tema	1 million	17.0m	700m	MPS (Bollore, APMT, GPHA)	Maersk
Abidjan II	1.4 million	18.0m	1,100m	Bollore / APMT / Bouygues	Maersk/ CMA CGM
Lome LCT	1.9 million	15.5m	2,400m	TIL-MSC/ China Merchants	MSC
Lome TTL	0.25 million	15.0m	450m	Bollore	None
Lagos-Badagry	2.0 million	16.0m	2,600m	APMT / TIL-MSC / Macquarie	Maersk / MSC
Lagos-Lekki	2.5 million	16.5m	1,250m	ICTSI / CMA CGM	CMA CGM
Kribi	0.8 million	15.0m	700m	Bolloré / CMACGM	CMA CGM
Pointe Noire	0.6 million	15.0m	800m	Bollore/APMT/Socotrans	Maersk
Total	12.05 million		11,200m		

Source: (DREWERY, 2015)

Existing ports are served through direct lines from Europe-East Asia to WCA ports via multiple port calls. The only exception is Mediterranean Shipping Company (MSC), which is using the Lomé Container Terminal (LCT) in Togo as a regional transhipment hub while serving the region. The LCT can handle container vessels with a capacity up to 14,000 TEUs (Egan, 2014).

This paper will discuss whether it will be profitable for governments and shipping lines investing in those new ports, and if those ports should be served through direct lines from Europe & East and Pacific Asia (EPA) to WCA ports via Direct Port Calls System (DPCS) or via a Hub & Spoke System (HSS) (like Algeciras or Tangier in the Northern region or Durban in the southern region).

Research questions: ***"What is the best option for shipping lines and governments to serve the West and Central African: a Direct Port Calls System or a Hub & Spoke System?***

In order to answer this question, multiple sub-research questions should be defined for guidance and help to narrow and clarify the purpose of this study. There are six sub-research questions, and they are as follow:

1. *Which data are available on trade between ports in the WCA region?*

This sub-research question explains from where we got the data for trade between the countries in the region. How these data are used to aggregate the ports, choose appropriate shipping routes and how cargo is allocated to each route? Furthermore, in Chapter 5.2 the countries and ports in the WCA region, each country in the region will be described separately in order to understand their economy, annual container throughput, maritime market and the importance of port infrastructures as a major driver of their economies.

2. *Is there any difference in viewpoint between governments and shipping lines? And which performance criteria of liner shipping network are relevant in this respect?*

To answer this question, in chapter 2 Literature review (section 2.4), we will state if there is any difference in the view points of governments and shipping lines while making decisions to choose where and why to invest in port infrastructures and explains the main differences and goals of each one.

3. *What is the difference between Direct Port Calls System and Hub and Spoke System?*

A literature of the differences between DPCS and HSS will be discussed in chapter 2 (section 2.3) to give an overview of the two systems when they are profitable to use one system over the other or use a combination of the two depending on the circumstances of each port and each route.

4. *From where cargo comes and in which amounts in WCA?*

In chapter 4 Data section 4.2 we will give a table describing the total trade between all the countries of the WCA region in TEU values, the table is a conversion of trade values from US $ to container value, the conversion method is explained in detail in section 4.2.

5. *What are the main characteristics to determine a Hub and Spoke port in WCA?*

The main characteristics used to determine the Hub & Spoke ports are chosen using a qualitative analysis, which are: the annual container throughput of the ports, the importance they play in the region as trade gateways for some landlocked countries and the port infrastructures, especially the draught which determine if the port chosen can be able to hoist the vessel elected in this study. Furthermore, the yard capacity which is a very important factor to assess if the port can handle the flow of large amounts of the new container flow coming from other ports.

6. *Which ports in the WCA region have the highest chance of becoming a hub port?*

1.3 Problem formulation and approach:

In this part we will focus on describing the approaches used to determine the shipping routes. First, we define the port aggregation method, then we combine the results from aggregating the ports in the WCA region with ship routing and cargo allocation methods to answer the research question.

1.3.1 Port Aggregation

The port aggregation aim is to make the route modeling for shipping companies very simple and that by combining ports (in the same country or region) with low container throughput in one major port to limit extra costs and time that could be produced while visiting all these smallest ports. Furthermore, this model gives more advantages to the chosen port to handle all these new flows and become a hub and spoke port in that country or region (Wardana, 2014). Large vessels would be needed to handle all the incoming cargo and also big investments in port infrastructures, although freight rates would become lower because of economies of scale, while port time and delivery time may increase because of the new schedules of big vessels (Wardana, 2014).

The study will use this model to assess the coming and domestic flow of containers between ports in the WCA region and assess which port would be chosen to aggregate those flows coming from neighboring ports, with regard of different characteristics such as geographical restrictions, draught, yard capacity, handling costs, port time, and towage fees (Wardana, 2014).

To solve the problem of port aggregation a location problem solution studied from the supply chain course we had this year, will be used to determine the optimal location with regard to costs. Furthermore, port specifications will also play a major role to help determine the candidate Hub & Spoke ports (Chopra & Meindl, 2013).

1.3.2 Ship Routing and Cargo Allocation:

The ship routing model gives more information's and details on how to optimize a number of routes in order to serve one destination, and how many vessels should be deployed to serve those routes (Wardana, 2014). Furthermore, every route distance and costs should be minimized efficiently and that by reducing or increasing the speed of the vessels in order to meet the schedule and reduce the voyage costs. Moreover, a basis criterion is that the ports (port A origin and B destination) served by the route should have the same characteristics to allow turn around trips between the two selected ports (Wardana, 2014).

The cargo allocation model is used to maximize profit in each route, after being determined by the ship routing model. Furthermore, the service provided by transporting one container from A to B is what generates the revenue (Wardana, 2014). Moreover, demand should exist between A and B as mentioned before in (Ship Routing), and the route should generate higher profits in order to be considered by shipping companies (Wardana, 2014).

Ship routing and cargo allocation are determined by the demand between two ports (A & B). Furthermore, they are highly correlated. However, if a route is served by a maximum number of vessels, another route should be determined in order to serve the remaining demand of the year (Wardana, 2014).

To solve the problem of ship routing, the routes are determined manually as all the ports in WCA are geographically in a linear sequence and are close to each other (in other words. So, the first port closer to the port of origin is the first served, the only exception is when the demand to or from other ports (ports of discharge) which have greater container volume. They are served first using not only one route but three more other routes (this is will be explained in details in Chapter 3: Methodology in section 3.3). Furthermore, when it comes to cargo allocation a heuristic problem will be used. These two problems will be discussed in details in chapter 3 (Methodology).

We also present a demand matrix to determine from where cargo comes from and the total throughput in TEUs transported between all the countries in the WCA region. Furthermore, we optimize the cost for the routes chosen and that by calculating the best optimal routes in terms of distance, voyage costs and operating costs.

1.4. Thesis Outline:

This paper is divided into 7 chapters, the first chapter defines the main problem, which concludes in the formulation of a research question, sub-research questions and how are we going to solve the problem mentioned. Then, in the second chapter based on those questions a literature is reviewed of similar research papers that have been done previously to tackle this similar topic. Furthermore, this chapter (second) will be divided into five parts. The first and second part gives a description on how ports are aggregated in order to simplify the ship routing design. Next, in the third part states the difference between DPCS vs. HSS. Then, in the fourth part describes the difference between governments and shipping lines point view. Moreover, the last (fifth) part gives a small summary of successful stories that used either a DPCS or HSS.

Furthermore, the third chapter describes the models (port aggregation, ship routing and cargo allocation) used to answer the research question.

Moreover, the fourth chapter describes the data such as: fuel cost, port dues, distance, ship chartering rate used in the calculations. The fifth chapter will give an overview of the ports characteristics in the region, based on those specifications the ports are chosen as Hub & Spoke port or eliminated. Furthermore, we will give description of the economy and container throughput of each country in the region and also the ports.

The sixth chapter gives an analysis of the results, after the aggregation of the ports and will describe the best routes and options that would be chosen by shipping lines. Furthermore, we will give a comparison between the two systems to answer our research question.

In the seventh chapter we present the conclusions and limitations of this paper, and also we give some suggestions for further research that should be done in order to have more accurate results.

Chapter 2: Literature Review of relevant works

In this chapter we first review relevant papers used to study and understand the economic characteristics, and trends of the WCA countries economy, container market and the port characteristics. Second, we discuss the location problem used by many researchers to solve the port aggregation problem. Third, we discuss literatures used in ship routing and cargo allocation methods. Fourth, we give literatures and papers discussing the difference between DCPS vs. HSS. Fifth, we discuss the difference in viewpoint between shipping companies and governments when investing in port infrastructures. And Sixth, we will give the main conclusions from the literatures that will be used in this paper.

In recent years many research have been done to assess container ship routing problems. The worldwide container traffic has increased dramatically in the last decades, and that pushed shipping lines to provide more complex and better services when transporting cargo and specially containers, while assuring higher profit and minimization of costs.

The papers used are the most cited and relevant papers for my research. Many of these papers used the same approach and methods (that will be used in this study) for different regions especially for the ship routing for the Europe – Asia route. Many papers were found but only 16 papers in total were used, which are the most relevant for this thesis.

Search terms: *West and Central Africa, port aggregation, ship routing, cargo allocation, Hub & Spoke System, Direct Port Call System, route design, ship scheduling, location problem, transshipment, profit maximization, port investments, shipping lines, governments, port aggregation.*

Ducruet & Notteboom (2012) study the different overviews on how to develop and design a liner service network. Their results show that a direct service is faster for the delivery of cargo. However, this lead to unutilized capacity of the vessel (overcapacity). Furthermore, they concluded that feeder linkage; the schedule of the services and rotation between the ports are the most important factors when it comes to shipping networks and cargo allocation. Wardana (2004) assesses how an appropriate route can be determined for serving the intra-regional trade in Indonesia in terms of profit optimization. He used three methods (port aggregation, ship routing and cargo allocation methods). Furthermore, he selected a 3,500 TEUs vessel depending on port restrictions to determine the hub and spoke ports in every region. The results show that there are three possible routes and that the second route should be chosen because it generates more profit and it is shorter than the other two routes. MLTC-CATRAM (2013) presents a full market study on container terminals in WCA region and the possible outcomes of the massive investments in port infrastructure in that region, which may result in overcapacity in the region by 2020. Moreover, it gives multiple information's about the current maritime services, container throughput by port, routes, shipping lines market share, types of vessels serving the region, ship-owners strategies, and details about ports infrastructures in the region.

This thesis will use the same methods and mainly the same structure as Wardana (2014) research paper to assess the WCA region.

After understanding the economic trends and port characteristics of the region, a literature review of the methods will be given below and it is divided into four parts. The first part is about port aggregation and why it should be used in this paper. The second part presents how ship routing and cargo allocation problems are solved using different methods. The third part describes related researches about the difference between DCPS vs. HSS. The fourth part, gives the main differences in the viewpoint between governments and shipping lines while investing in port infrastructures.

2.1 Port Aggregation

In this part we will focus on how the location problem is used in to solve port aggregation problems. The location problem is used because it helps to choose the optimal location of a plant; a factory or a warehouse in order to minimize production and transport costs between two locations (origin and destination). In logistics this problem is known as a transshipment problem (Wilson, 2005).

Wilson (2005) uses a heuristic model combining the distance minimization with a double constrained gravity model while using populations as proxies for freight demand of the cities (origins and destinations) to help managers determine optimal locations based on customer service requirements. Vygen (2005) describes in a very simple form six different methods (Fermat-Weber problem, Greedy & Primal-Dual Algorithms, Reductions for more general problems, Local Search and Incapacitated & Capacitated Facility location problems) that can be used to solve the location problems, which normally in practice and real life are more complicated and they are usually solved by adding constraints to the main problems or by setting different objectives (Vygen, 2005).

2.2 Ship Routing & Cargo Allocation:

We start with Cho and Perakis (1996) study the optimal route design and fleet size for a shipping company, and in order to solve that problem they use a linear programming solution. Moreover, in order to expand the fleet size, they use a mixed integer programing model. Xianlin et al (2000) use the same model as Cho and Perakis (1996) to determine the optimal fleet deployment plan and the number of vessels to be added to the existing fleet. Man (2007) uses an algorithmic solution to solve the same problem, and that by sorting the routes based on their length. Furthermore, selected the shortest routes and allocated the maximum demand to those routes. A drawback of this method is that it is not possible to define an optimal solution as long as you choose only short routes. Man (2007) study how to optimize the routes between Europe and Asia, he uses the O/D Demand matrix between selected ports in that region and the Travelling Salesman Problem (TSP) with a heuristic method to solve the problem of cargo routing and ship scheduling. Furthermore, he defines the first port to be served using a set-covering problem by a specific route, taking into account demand allocation. Meer (2009) using the same methods as (Man 2007) study ship scheduling and cargo allocation (Europe-Asia trade), the routes that generate the most possible profit by the two methods are then chosen to allocate demand. He then studies the outcomes using different speed for the different routes and then compared the results with Man (2007) results. Mulder and Dekker (2013) combine three methods, which are fleet-design, ship scheduling and cargo routing problem, in order to maximize profit of an X shipping company. They only consider the intra-regional demand because the revenue is small, even though this model can also be applied to regional demand. The aggregation of ports is done using a linear programming model in order to decrease the size of the problem. The results from the port aggregation are used as new data to solve the other three problems.

2.3 Comparison between DPCS vs. HSS:

Pálsson (1998) assesses the costs and benefits of changing the way the WCA region is served from a Direct Port calls system to using a Hub & Spoke System in the WCA. The study shows that the difference of using the two systems is negligible in the region. Furthermore, that any cost reduction will be in the benefit of the hub-spoke port, and thus would result in an increase of costs for the other ports. Francesetti et al. (2002) explain the advantages of using a HSS rather than DCPS in the Mediterranean. They used an analysis that compares transport costs using both methods while serving the Mediterranean region. Their study shows that in terms of unit cost transported, the HSS is more advantageous than multiport calls system, especially if the transport at sea and the handling services are done by the same company. Imai et al. (2009) study the same topic by using the service network design and container distribution for comparing the Europe-Asia and Asia-North America trade routes. They used a conventional ship for the multiport calls and a mega-ship for the Hub & Spoke port. Moreover, they used two methods, the service network design and container distribution using different numerical calculation for both systems. In their research they found that HSS decreases the cost of transport for shipping companies and that multiport calls generate huge total cost.

African Bank Report (2016) explains some key lessons from the development of regional transshipment hubs in Africa, and their importance for the regional economic integration of the African countries and its wider integration in the world trade system.

2.4 Difference in the Viewpoint between Governments and Shipping Lines while investing in ports:

Governments always take different approaches while assessing a public investment, and especially port infrastructures (PPIAF, 2017). A port is considered as a combination of both a private and a public good. The port generates direct and indirect benefits to the economy and that through its operations by generating high values of trade flows, and attracting cluster industries that want to benefit from tax reductions, low transaction costs and reduce transportation costs (PPIAF, 2017). Furthermore, the port has a multiplier effect that pushes or justifies government directly investing in its construction (PPIAF, 2017). Port investments are directly financed with government investment budget, special funds, private investors, or through international institutions funds loans (PPIAF, 2017).

The government may invest in the development of port infrastructures for one main reason, which is to increase national economic welfare (entire nation benefit) (PPIAF, 2017). These investments can be sometimes over-estimated or under-estimated, depending on the degree of government interference in the operations of the port (PPIAF, 2017). Which sometimes should be leased or contracted out to private companies, while controlling the operations through a public or private port authority (PPIAF, 2017). Those private companies can be stevedoring companies, port / terminal operators or handling services companies that seek more microeconomic goals such as: market share growth, and profit maximization than macroeconomic goals (PPIAF, 2017).

In recent years' governmental port authorities are facing a fierce competition with big shipping lines and terminal operators that emerged and created strategic alliances and sometimes even horizontally and vertically integrated (PPIAF, 2017). Showing their will to control all the transport chain from A to Z. Especially with the introduction of third generation's vessels, and the need to secure berthing and a big filling capacity for those massive container vessels. Port authorities can sometimes seed against big terminal operators' threatening to leave a port. The port management structure may therefore be changed to one of the following models: service port, tool port, landlord port or to a fully privatized port (PPIAF, 2017).

From the point of view of shipping lines, they commonly lease terminals from port authorities, but there are two main conditions in order for the lease to be successful for both parties (PPIAF, 2017). Firstly, that the lessee should be a major customer that insures high volumes of cargo (PPIAF, 2017). Secondly, that the port authority should have a second terminal leased to another shipping line or terminal operator with the same specifications in order to prevent monopoly of the terminal operations, and that may create a conflict of interests between port authority and the national economy (PPIAF, 2017). Because, shipping lines as a result of financial or trade changes may change or shift the routes, decrease or even stop their services. Furthermore, they may even create partnerships or alliances with other shipping lines, thus may result in changes in service schedules or even negotiation with competitor ports in the same region or area (PPIAF, 2017). Moreover, the service schedules may also shift for international policy changes (PPIAF, 2017).

These literatures give a general overview about previous studies done to tackle the same topic in the WCA and Europe-Asia regions. Some of the methods used by the researchers can be utilized to construct our study framework. This part was divided to four parts, each part explaining different method, and how to solve them. The papers utilized did all tackle the same problem, how to minimize the cost of transport in a shipping network from Europe to Asia. The same approach will be used to analyze the WCA region.

To solve the first method that is port aggregation, the location problem will be used as explained by Vygen (2005) and Wardana (2014) using a qualitative analysis based on the port characteristics explained in chapter 5 section 5.1.

Concerning the ship routing and cargo allocation will be solved using the same approach of Travelling Salesman and heuristic problems as previous researchers. The first thing that was determined in all papers was the yearly demand for the region; with that yearly demand the cargo is allocated for each port. Furthermore, concerning the ship routing the schedule that was set for each port was fixed, which means that the vessel comes once or twice in a fixed day of the week or the month (depending of the frequency, profitability and also to meet the demand for each port).

Chapter 3 Methodology:

This chapter will give a description of the three methods used in this thesis (port aggregation and the ship routing & cargo allocation). The first method will analyse the location of the hub ports along the WCA region. Then, the second method will determine the ship routes and cargo allocation. In other words, the results from the first method will be used as primary data to determine the ship routing and allocation of cargo especially for the Hub & Spoke system. This thesis will use quantitative model but a qualitative analysis will also be used to adjust the result from the port aggregation to real life outcomes. The ship routing will be done manually using the same approach as the TSP using data and information's from Chapter 4 (data).

3.1 Main Problem

The main goal of this thesis is to present an efficient way to optimize the shipping routes serving the WCA region from Europe and Asia, and to maximize the profit of those routes. Thus, by combining three methods which are: port aggregation, ship routing and cargo allocation.

The vessels chosen will follow a fixed shipping routes and serve a fixed number of ports (defined by the route). A route is defined as a set of ports a ship should stop at. Furthermore, it is a two-way trip (one voyage). The ship is scheduled to stop on a port in a fixed day of the week. Moreover, the routes chosen should meet all the demand from the port of origin to the port of destination (A to B). The revenue is generated from the transport of the containers from origin to destination, thus by multiplying the number of container in the O/D matrix with the price of handling those containers in the port of load and port of discharge, the price of handling one container in each port will be given in (Chapter 5 section 4.7). Then, all the costs such as: port dues, voyages costs, fuel costs, ship charter cost (all these informations will be given and defined in chapter 4 data) are subtracted from the revenue, which result at the end in a profit per route.

The objective function employed in this paper is expressed as the following (Wardana, 2014):

$$max \sum_{s} \sum_{i,j\epsilon N} RT_{sij} - C_S \sum y_s - C_F \sum_{i,j\epsilon N} x_{sij} - C_P \sum P_s - C_H \sum_{i,j\epsilon N} T_{sij}$$

$s.t.$

$$\sum_{s} T_{sij} \leq D_{ij}$$

$$\sum_{s\epsilon k,l} T_{sij} \leq Cap_{kl}$$

$$T_{ij} \geq 0$$

$$y_i\ integer$$

Here below are the main parameters that are used:

R	Revenue for the transportation of one TEU in each port
C_S	Ship charter rate per year
C_F	Fuel costs per nautical mile
C_P	Port dues per port visit (Gross Tonnage per Vessel)
C_H	Handling fees per one TEU handled
D_{ij}	Total transport demand in TEUs from port *i* to *j*
$Cap_{\ kl}$	Maximum ship capacity per voyage route

The three decision variables are stated as the following:

T_{sij}	Total number of containers unloaded from port *i* to j through route s in one year
	Total number of containers loaded from port *i* to j through route s in one year
y_s	The number of ships deployed in a route S.

This objective function is defined to maximize the profit of a defined route while serving the WCA region. The first parameter of the objective function is revenue. The revenue is generated from the service of transporting a container from A to B as explained in the beginning of this chapter. The second parameter is the ship charter cost, which is defined as the total ships deployed in a route multiplied by the ship charter time rate per year (For vessel with a capacity of 3,500 TEU's and 1,700 TEU's). Third parameter is the fuel cost; it is calculated by multiplying the total distance of a route by the fuel cost per nautical mile, with the number of vessels, times the number of trips per year. Then, the fourth parameter is the port dues it is calculated by multiplying the port dues rate of each port, by the number of port visits by a ship in a route. The fifth (last) parameter is handling fees it is also calculated multiplying the number of container handled in a port by the rate per move in each port.

The constraints of the objective function are eight and are defined as follow:

The first constraint defines that the total demand per year should be equal to the total of cargo transported within a year period.

The second constraint defines that the number of containers loaded in the port of departure cannot exceed the maximum capacity of the vessel.

The third constraint defines the Ys number of vessels should be an integer number.

The fourth constraint define the total cargo in a ship should be greater or equal to zero (in other words should not be negative).

The fifth constraint defines that the cargo capacity of the ship should be less or equal to zero (should be negative).

The sixth constraint defines that the total of containers loaded in a ship from a port has to be greater or equal to zero (should not be negative).

The seventh constraint defines that the total of containers unloaded in a port has also to be greater or equal to zero.

The eight constraint defines that the total unload minus the demand from a port I to j has to be equal to zero, and also the total load minus the supply from port i to j has to be equal to zero.

3.1.1 Main Problem Assumptions:

Many assumptions have to be made in order to simplify the model and the calculations, those assumptions are made to calculate the revenue, cost and profit for both systems (HSS and DPCS). The main model assumptions are as follow:

- The total demand is for a whole year period.
- There is no demand and supply between ports in the same region or in the same country (even if in reality there is demand between ports of the same country).
- Not all the containers should be handled, in other words the demand may not be satisfied if some routes do bring losses (no profit) to the shipping company.
- The time of a voyage is related to the distance traveled.
- The speed is fixed for all vessels which is 18 knots per nautical miles for the vessels used in both the Hub and Spoke system and the direct call system.
- The port time and waiting time is the same for all ports, even if in reality it is not true (each port have its own specifications, such as channels, estuaries, tide and handling equipment's).

- The port time is calculated assuming that the ship will be loading or offloading all the 3,500 TEUs used for the HSS while using two Ship to Shore Crane (STSC).

- The crane productivity in all the ports is the same which is 17 TEU per hour for one STSC. This number is taking from the average crane productivity of a crane in the WCA ports. For Rotterdam and Shanghai, the same average crane productivity is taking only for the simplicity of the model calculations.

- For the port time of the DCPS using the 1,700 TEUs vessel the same assumption is used as the HSS, with only one STSC and with the same average crane productivity.

- The ship size for the transshipment system is fixed to 3,500 TEU's due to ports restrictions and to simplicity of the model and calculations.

- The ship size for the direct routes is also fixed to 1,700 TEU's, due to ports restrictions.

- The ship calling is based on the number of ships deployed for each route and also depends on the number of trips per year.

- The number routes are not limited to satisfy all the demand.

- The number of ships are not limited also to satisfy all the demand.

- The port dues are fixed for all the ports selected for the HSS for simplicity, using an average rate (the port dues are described in table Chapter 4: Section 4.5 in € euro, a conversion is done to US $ dollar as all the costs and the revenue are in US $).

- The port dues of the DCPS are not fixed, they are calculated using an average rate for all the ports selected for each route. The same thing apply also to the HSS.

- The ship costs are fixed all over the year based on the ship charter time for a year (charter time contract is used because it includes all the costs related to the ship for the whole year).

- The charter rate is calculated on a yearly basis, the number of ships deployed to serve all the routes for a specific system will be the same (3,500 TEUs for the HSS, the 250 TEU vessel for the feeder network, and the 1,700 TEUs for the DPCS).

- The handling fees in all the ports are the same using an average rate of $192/ per move.

- The fuel cost per nautical mile for the 250 TEU vessel is assumed to be \$20.5/NM. Regarding the 3,500 and 1,700 TEU it is assumed to be fixed for both vessels \$30.5/NM.

3.2 Port Aggregation

As mentioned before in the problem formulation (Chapter 1: Section 1.3), the location problem method will be used to solve the port aggregation. This method is also known as the facility location problem, the plant location problem or warehouse location problem. Supply chain managers, use the location problem analysis to determine where a facility or warehouse should be located or opened while considering minimum transportation cost. Furthermore, the location of the warehouse or plant should generate economies of scale while ensuring high responsiveness to customers' demand efficiently. Moreover, there are other factors that also should be considered by managers while assessing whether to open or not a plant in a specific region, which are the political, economic situations and the infrastructures condition in that region (Vygen, 2005).

Chopra and Meindl, (2013) present other characteristics that should be taken into account, such as the capacity of the warehouse or plant to receive goods (storage) and the distribution to customers as a distribution center. Moreover, the utilization of the facility should be high in order to satisfy the demand fluctuations, even if having high stocks may decrease efficiency.

In shipping the location of a port in order to be chosen as a Hub & Spoke port is determined by many characteristics and especially the handling cost (transshipment cost), the port productivity and the port specifications (draught and yard capacity). In this thesis the Hub and Spoke port will have the major role to determine which of the ports in the WCA region is considered as a Hub and Spoke port. The Hub & Spoke port will be positioned in a strategic location to serve several small ports as long as the WCA coast is too long.

Furthermore, the Hub & Spoke ports are chosen based on their accessibility by big container vessels (in this thesis the vessel used is a 3,500 TEUs), the nautical accessibility, and the draught. Furthermore, as mentioned above the yard capacity will also play a major role, as the ports will handle big number of containers. Moreover, the berth length and the crane capacity are also major determinants.

A linear programming model is used to determine the Hub & Spoke ports in the WCA, and it is defined as follow (Wardana, 2014):"

The variable define that x_i is 0 or 1 parameter. Xi is 1 if the Hub port is located in region i, or 0 otherwise.

$$x_i = \begin{cases} 1\ if\ main\ port\ is\ located\ in\ region\ i \\ 0\ otherwise \end{cases}$$

The objective function has to be set as the following, and that to minimize the number of Hub and Spoke ports in the region.

$$Min\, x_1 + x_2 + x_3 + \cdots + x_n$$

The linear programming model requires one constraint to be determined for each port in the region, because the Hub ports can only be located in region i if the port is too close to another port.

$$
\begin{aligned}
&s.t.\\
&x_1 + x_2 + x_3 + \cdots + x_n \geq 1\ Port\ 1\ Region\ 1\\
&x_1 + x_2 + x_3 + \cdots + x_n \geq 1\ Port\ 2\ Region\ 2\\
&. \qquad\qquad\qquad\qquad\qquad .\\
&. \qquad\qquad\qquad\qquad\qquad .\\
&. \qquad\qquad\qquad\qquad\qquad .\\
&x_1 + x_2 + x_3 + \cdots + x_n \geq 1\ Port\ n\ Region\ m\\
&x_1 = 0, 1\\
&i = 1, 2, 3, \ldots, n.\text{”}
\end{aligned}
$$

The distance between the ports and the constraint port n should be set. For instance, the hub port location should be situated 100 to 200 nautical miles from the constraint port.

The results from the model are given after setting the constraints and running the model. The results will give a number of chosen hub ports along the WCA coast. Then the aggregation of demand can be processed from small ports to the chosen ports.

3.3 Ship Routing & Cargo Allocation

As mentioned before in chapter 1 section 3.1.2 the ship routing is done manually without using the TSP as all the ports are in a line. The distances from port A to B is closer than from port A to C. the only exception is that some routes may serve directly port C or port D if the demand is greater than port B. Port B also, may not be served if the container volume that will be transported is not enabling the shipping company to make profit or at least compensate its costs (as mentioned in the main problem assumptions).

To determine the routes, we first made a Demand / Supply matrix (O/D Matrix). We allocate the cargo on each route based on the revenue. First we made a constraint, that defines that the supply and the demand from port of origin (which in our study Rotterdam for Europe – WCA and Shanghai for Asia – WCA) to another port should not exceed the capacity of the vessel. In other words, the vessel has a limit of its capacity (for instance 3,500 and 1,700 TEUs vessels), the load from the port of origin to destination should not exceed that, not only for one port but for all other destinations determined to be visited by the vessel in a specific route. As the vessel arrives to its first destination the containers (Demand) are offloaded and the supply of that port to other ports is then loaded (the number of containers loaded cannot exceed the ship capacity). This is done in a continuous basis for all the ports until the vessel reaches its final destination, then all the cargo is then offloaded (Wardana, 2014). Furthermore, some ports may be visited by the vessel even if they have no demand, but because they are in the ship route, some slots are still available or because cargo should be directly loaded in that port (Wardana, 2014).

The routes are defined as round trips for instance if the trip starts from Rotterdam (RTM) we put as 1 and then Dakar (2), then Abidjan (3) then come back to Rotterdam (1). If the ship should go back to Dakar, then its (2) and after that a way back to Rotterdam (1). The last port in our route definition cannot be visited twice (offload and then load) this would be counted as only one port visit (Wardana, 2014).

In this study the profit is calculated by subtracting the revenue of the containers transported, the handling costs of all the transported containers (load / offload), the port dues depending on the number of vessels deployed for each route and the number of trips, the fuel cost which is engendered from the distances travelled by the vessels, and the charter time contract depending also on the number of vessels deployed (Wardana, 2014).

Furthermore, the containers that are transported from port of destination to port of origin should be subtracted from the original demand matrix. Then, the most optimal routes (with highest profits) are listed and will be the ones used in the analysis (Wardana, 2014).

An example is giving to explain how the allocation method is done for the first route from Rotterdam to Dakar. We have a first route that is defined, for that the ship visit all the ports in a round trip, the first route is: Rotterdam – Dakar – Abidjan – Lome – Cotonou – Pointe Noire – Cotonou – Lome – Abidjan – Dakar – Rotterdam, with a total distance of 10,018 nautical miles. The results from the cargo allocation for the first route show the following results:

1. The vessel is fully loaded from Rotterdam by its yearly capacity (supply) then the Dakar demand is offloaded.
2. The supply from Dakar to Abdijan, Lome, Cotonou and Pointe Noire is then loaded, after that the vessel visits Abdijan and unload all the demand of the port from Rotterdam plus the demand of Dakar.
3. The supply from Rotterdam, Dakar and Abidjan to Lome is unloaded and then the demand from Lome to the following ports in the route is then laoded (Cotonou and Pointe Noire).
4. The same process as the previous ports is also done, the supply from the port of Rotterdam, Dakar, Abidjan and Lome is then unloaded in Cotonou and then we load the Demand for Pointe Noire port only from Cotonou this time.
5. Then, the cargo from Rotterdam, Dakar, Abdijan, Lome and Cotonou is unloaded, and the supply to the port of Rotterdam and to the same is done for the reverse route.

3.4 Evaluation:

In this chapter we explained the methodology used in this paper. The first method is the location problem, which is used to define the Hub & Spoke ports with the qualitative analysis (see chapter 6 port aggregation). All the demand is then gathered from small ports in the WCA coast line to the chosen Hub ports, and then a new container demand is defined. Furthermore, from these new demands, the routes and cargo allocation can be determined.

The routes are defined manually as mentioned previously, then the cargo is allocated to each port. Furthermore, all the data and information are entered to excel spreadsheet, to define the cargo allocation and the most profitable route. We did take into all the costs while making the model calculations, as the objective of this study is to assess the most profitable system for serving the WCA region. An objective function is determined in Chapter 3.1, with all the decision variable and constraints.

In this thesis three countries are not considered because their ports and trade flow is too small, and there are small information's available about their trade and container throughput. These three countries are: Cape Verde, Sao Tome y Principe and Mauritania.

The port of Kribi in Cameroun is not also taken into account because no information's about the port characteristics since the termination of its construction in 2015. There are no activities inside the port and the concession is not giving to any terminal operator or handling services company to present.

Chapter 4 Data:

In this chapter we present and discuss the data available for this study. We first start with distance matrix data between ports in section 4.1, then, second we give the regional demand between countries in the WCA region in section 4.2, and third we define the speed and specifications of the vessels used to serve the routes in section 4.3. Fourth, we determine the revenue of each route depending on the actual freight rates for the transport of one TEU in section 4.4. Then, fifth, we define the fuel cost formula and price based on vessel engine to determine the daily fuel consumption in section 4.5. Sixth, we determine the port dues and handling costs in the WCA region in section 4.6. Seventh the actual ship charter price for the vessels chosen to serve the region in section 4.7. Ninth, the average port time spent by the vessel in each port in section 4.8.
In this thesis all the costs are expressed in US dollar to make them comparable. But, the actual costs are in a variety of currencies and fluctuations in conversion rate may affect the outcomes of this paper.

Furthermore, as mentioned earlier in the literature review section 2.4 (Chapter 2) this thesis is using same data calculations and structure as Wardana (2014) research paper formulas.

4.1 Distance:

The distance is calculated between each of the ports selected from port of origin to port of discharge (destination), and that by using a distance calculator from (sea-distances, 2017). If all distances required are not found in that website, other websites are used such as (marinetraffic, 2017), (portworld, 2017)and (searoutes, 2017). The distances are in nautical miles (NM). The distances between all ports selected in this paper can be found (see Appendix: 4.1).

4.2 Container Flow (Total Imports & Exports between WCA Countries):

In order to determine the cargo allocation and routes network design for serving the WCA ports. First of all, we have to find the volume in container flow traded (TEU) between each port selected. Those data are found in the table in Appendix 2. The O/D matrix of the region is generated using trade values in US $ (Total export and imports) between the countries selected in this study. The data are extracted from (WITS, 2017). A conversion from trade values in US $ to TEUs is done using an average container value of 68,412$/TEU (OceanNetwork, 2017). After the conversion, a containerization ratio is used to determine the most likely number of TEUs shipped between the selected countries in the region. The containerization ratio is extracted from (WTO, 2017), and also on own assumptions based on the type of products exported from each country. For instance: Angola oil exports represents 97% of the country total exports, so the ratio of containerization exports is low 5% and imports is high because a variety of products are imported such as: construction materials, food and electronic products).

The whole trade volume and containerization ratio table between all the countries in the WCA is presented in Appendix 4.2 & 4.3:

4.3 Speed and Ship specifications:

For the simplicity of the model, average design ship speed used in this model is 3,500 TEUs container vessel for the HSS, and the 1,700 TEUs vessel for the direct calling system. Furthermore, for the feeder network a 250 TEUs vessel is used for all the routes. According to data from (Dekker, 2017). From the table 2 below, we can see that the average maximum speed is 18 knots for both vessels, while taking into consideration slow steaming and simplicity of the model calculations.

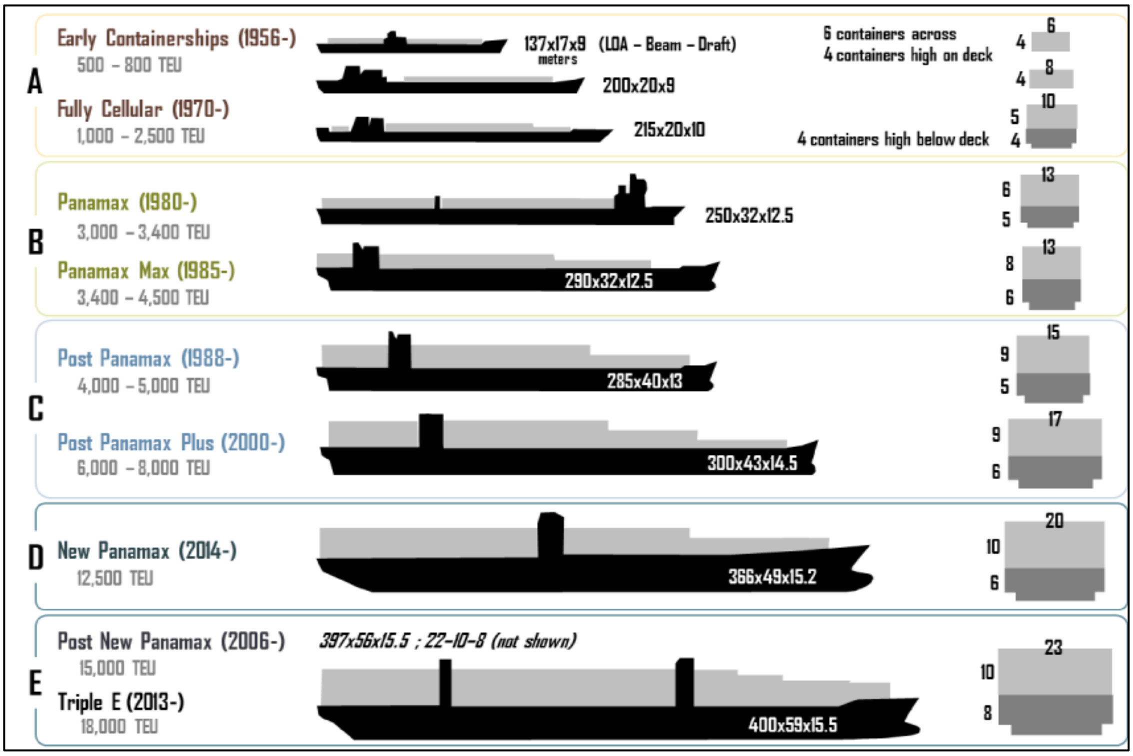
Table 2: Available ship types and their specifications

Vessel:	Capacity [TEU]:	Design Speed [kn]	Min. Speed [kn]	Max. Speed [kn]	Idle Costs Per day [$]	Fixed Costs daily [$]	Fuel costs [$]/nmi
Feeder 450	900	12	10	14	1440	5000	39.17
Feeder _800	1600	14	10	17	1500	8000	42.32
Panamax_1200	2400	18	12	19	2400	11000	72.92
Panamax_1750	3500	18	12	20	2700	15000	76.39
Panamax_2400	4800	16	12	22	3180	21000	89.69

Source: (Dekker, 2017)

According to many reports there are multiple vessel sizes that are used for serving the WCA region varying from feeders with a capacity of 500 TEU’s to 8,000 TEU’s in the port of Lomé since 2015 (the port can handle vessels up to 14,000 TEUs as mentioned in chapter 1). Since many years shipping lines serve the WCA market with only small feeders due to geographical restrictions of the ports. Furthermore, ports characteristics, the expensive handling fees and port dues costs in many countries, are another factor, as can be seen from the tables 3 and 4 (See 4.6 section: port dues and handling costs). In chapter 5, we give more details about the port specifications in each country of the WCA region such as maximum draught, yard capacity, quay length, number of cranes, etc. thus, would help us assess which type of vessel to use for the calculation in this thesis. The figure 2 below gives an overview of the evolution of containerships by (Ashar & Rodrigue, 2012).

Figure 2: The evolution of containership



Source: (Ashar & Rodrigue, 2012)

4.4 Revenue:

The revenue figures are gathered from the average rate of a full container from Europe-West Africa (searates, 2017) and (icontainers, 2017) and also from China to West Africa for one 20" TEU (ShanghaiShippingExchange, 2017). We multiply the total number of containers in the O/D matrix, by the ocean freight rate to each port (destination).

The revenue for each port is then calculated by multiplying the revenue per container transported by the total number of containers handled in that port (see in Appendix the freight rates matrices for each system and for each port based on data subtracted from "sea rates" and "icontainers" and some rates are not found, but are estimated based on the neighbor ports).

4.5 Fuel Cost:

The fuel cost is one of the most important costs when it comes to calculating voyage costs; it represents 47% of voyage costs (Stopford, 2009). This cost can be calculated based on the distance between port of origin and port of destination. A fixed bunker rate would be used for all the shipping routes for simplification. In order to calculate the bunker cost for each trip, the vessel consumption per nautical mile should be known. According to Wardana, (2014) the vessel fuel consumption is calculated as follow:

$$C_s = k.s^3$$

Where:

C_s = Fuel consumption (tons per day)

k = Technical coefficient is 180 (ship design, engine efficiency, maintenance, etc.). Based on 3,500 TEU container vessels.

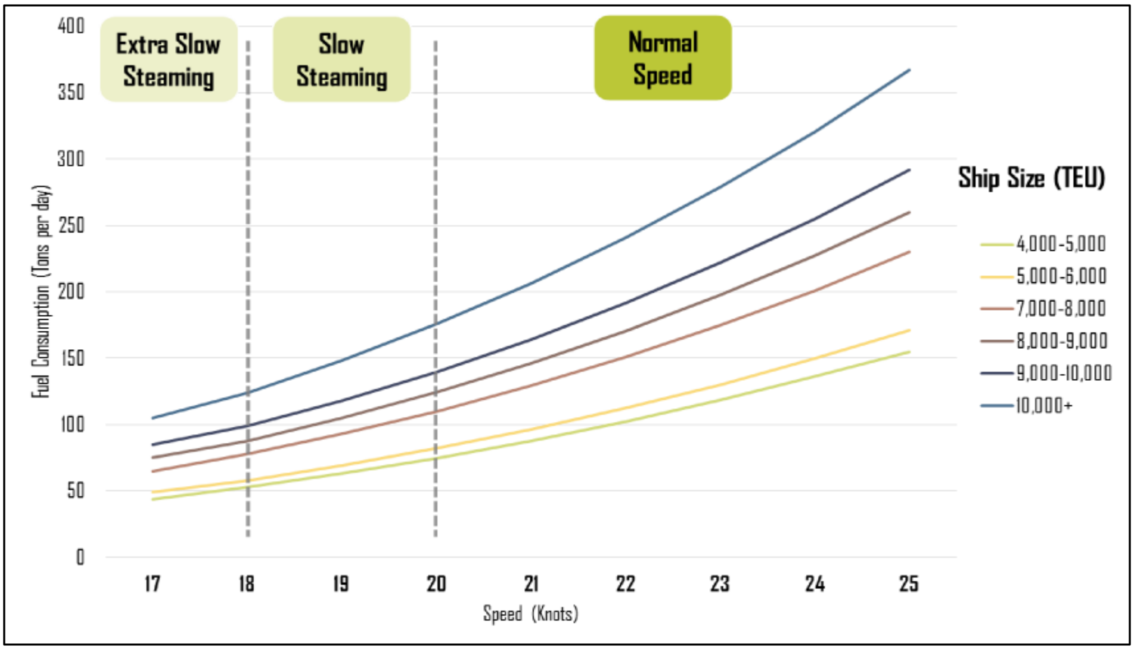
s = Speed (nautical mile per hour)

In this thesis, speed is assumed to be fixed 18 knots, according to table chapter 4 section 4.3) which specifies that the maximum design speed for a 3,500 TEUs to be 18 knot (Dekker, 2017).

Therefore, the fuel consumption of a 3,500 TEUs container vessel used in this paper with an 18 knots design speed is 50 tons per day.

A comparison of the results found by the calculations using Wardana, (2014) formulas, could be compared with a graph in the figure 3 below:

Figure 3: Fuel Consumption per Ship Size



Source: (Notteboom & Carriou, 2009)

The graph represents the fuel consumption per ship size, of a study made by (Notteboom & Carriou, 2009). It matches the results of the calculations using the Wardana, (2014) formula and shows that average daily fuel consumption for container vessels with a capacity of 4,000 – 5,000 TEU's and with an average speed of 18 knots, can reach approximately 50 tons/day.

Thus, the fuel consumption is obtained, and in order to calculate the fuel cost per nautical mile, the fuel consumption has to be multiplied by bunker price and divided by speed and 24 hours. The formulation can be stated as the following according to (Wardana, 2014): "

$$FC = \frac{C_s \cdot Fp}{s \cdot 24}$$

Where:

FC = Fuel Cost

Fp = Fuel Price."

The fuel price (IFO380) is 289.50 $/MT based on the market rate in the port of Rotterdam 04 July 2017 (Ship&Banker, 2017).

Thus, the fuel cost per nautical mile calculated from the formulation is 33.5$ /NM.

The same fuel cost per nautical mile is used for the 1,700 TEUs vessel.

The fuel cost for the 250 TEU vessel is assumed to be $20.5/NM.

4.6 Port Dues & Handling Cost:

The table 3 below presents the port dues in different countries in the WCA region; the prices are expressed in Euro (€). We can notice from the table that the tug fees may vary from 1,005 Euro in Banjul to 17,987 Euro (€) in Monrovia. Furthermore, the pilotage fees may vary from hundreds of euros in (Banjul, Takoradi, Tema, Lomé) categorized as small ports to a range of 4,000 to 5,000 € euros in ports like (Monrovia, Douala, Port-Gentil) for the reason that in some ports the vessel may have to navigate through the rivers (MLTC/CATRAM, 2013). Moreover, the port dues vary a lot from 744 Euro (€) in San Pedro to 27,841 Euro (€) in Tin-Can (Lagos), this huge difference may be explained that some ports still charge the port dues based on merchandise and not on the Gross Tonnage of the vessel (MLTC/CATRAM, 2013)

Table 3: Port dues and services for ships (in EURO €)

	Tug fees	Pilot fees	Mooring fees	Port dues	Total
DAKAR	**2729**	**2822**	**341**	**6510**	**12402**
BANJUL	**1005**	**555**	**122**	**22218**	**23900**
CONAKRY	**7974**	**2779**	**128**	**0**	**0**
FREETOWN	**0**	**0**	**0**	**20284**	**20284**
MONROVIA	**17987**	**4996**	**600**	**4336**	**27919**
ABIDJAN 1	**2592**	**4237**	**700**	**4476**	**12005**
ABIDJAN 2	**2592**	**4237**	**700**	**2952**	**10480**
SAN PEDRO	**2592**	**2729**	**910**	**744**	**0**
TAKORADI	**2262**	**889**	**291**	**2571**	**6012**
TEMA	**2262**	**889**	**291**	**0**	**_**
LOME	**2850**	**940**	**183**	**0**	**_**
COTONOU	**3570**	**1683**	**468**	**2342**	**8063**
TIN-CAN	**0**	**0**	**0**	**27841**	**27841**
LAGOS	**0**	**0**	**0**	**19963**	**19963**
PORT HARCOURT	**0**	**0**	**0**	**26660**	**26660**
DOUALA	**2823**	**5538**	**573**	**9951**	**18884**
BATA	**5076**	**1296**	**1693**	**4741**	**14231**
MALABO	**9911**	**2085**	**183**	**4302**	**19797**
LIBREVILLE	**4024**	**7222**	**543**	**16517**	**28306**
PORT-GENTIL	**4383**	**4856**	**543**	**7231**	**17012**
POINTE-NOIRE	**6313**	**1416**	**0**	**2850**	**10579**
LUANDA	**4205**	**1626**	**0**	**7878**	**13709**
WALVIS BAY	**1513**	**1549**	**0**	**0**	**_**
Total	**89650**	**63510**	**12612**	**321428**	**454973**
Median	**2592**	**1549**	**291**	**4406**	**13059**
Average	**3091**	**2190**	**435**	**11480**	**16249**

Source: (MLTC/CATRAM, 2013)

The table 4 below presents the rates paid for a 20” and 40” TEU Entering the port (E) or Leaving the port (S) either full (P) or Empty (V) (MLTC/CATRAM, 2013). This table does not show a big difference in prices between the ports; in average the port of Douala is less expensive for the handling of both the 20” and 40” TEU than other ports in the region (MLTC/CATRAM, 2013).

Table 4: On Board handling ((in EURO €)

	Manut bord							
	20				40'			
	E P	E V	SP	SV	E P	E V	SP	SV
Dakar	110,00	71,00	110,00	71,00	140,00	89,00	140,00	89,00
Lomé	?	?	?	?	?	?	?	?
Tema	63,61	50,48	63,61	50,48	120,15	90,87	120,15	90,87
Abidjan								
Cotonou	83,85	30,49	83,85	30,49	121,97	53,36	121,97	53,36
Lagos								
Douala	79,00	65,00	79,00	65,00	79,00	98,00	79,00	98,00
Pointe-Noire								
RDC	87,96	0,00	87,96	0,00	131,93	0,00	131,93	0,00
Libreville	90,00	50,00	90,00	50,00	135,00	80,00	135,00	80,00
Walwis								

Source: (MLTC/CATRAM, 2013)

The table 5 below represents the rate for the quayside handling. We can notice that there is big difference in prices compared to the previous table (on-board handling). The port of Tema offers the cheapest quayside handling costs, while the ports in the Republic Democratic of Congo are relatively more expensive (MLTC/CATRAM, 2013).

Table 5: Quayside handling (in EURO €)

	Quay-Side Handling							
	20"				40"			
	EP	EV	SP	SV	EP	EV	SP	SV
DAKAR								
LOME	129,59	3,05	53,36	3,05	144,84	6,1	83,85	6,10
TEMA	57,56	56,1	50,14	41	94,69	83	78,84	62,5
ABIDJAN								
COTONOU	114,35	0	114,35	0	189,05	0	189,05	0
LAGOS								
DOUALA								
POINTE NOIRE								
RDC	367,5	61,5	526	61,5	367,5	123	526	123
LIBREVILLE	160	20	160	20	240	40	240	40
WALVIS								

Source: (MLTC/CATRAM, 2013)

A port handling table can be seen in Appendix for each port in the WCA region, with prices in US $ for a container move. The handling fee for the port of Shanghai and port of Rotterdam are subtracted from the internet (Dailychina, 2017) for Shanghai which is estimated to 95$ per a container move and (CMA-CGM, 2016) for Rotterdam which is estimated to be 120 $ after the conversion from Euro (€) to US ($) Dollar.

The handling fee for one TEU in this thesis is assumed to be $ 192 for all handling calculations, this amount is obtained based on an average rate of all ports handling fees for the simplicity of the calculations.

4.7 Ship Charter

After selecting the appropriate vessels type to serve the WCA region based on the port specifications and ship characteristics. The ship charter cost is now determined.

There are three different types of ship charter contracts, which are: Time charter, bareboat charter and voyage charter. In this thesis we will use the time charter contract as long as it covers all the costs (operation, administration and voyage costs) for the simplification of the calculations. In the time charter contract the vessel is hired for a specific time period in this thesis this period will be one year.

The time charter cost will be considered as fixed in order to calculate the profit. The total cost per year is calculated using the total number of days during a year (365 days), multiplied by the daily charter rate that is 8,443 US $ for a vessel of 3,500 TEUs used for the HSS and a daily charter rate of 7,381 US $. These two rates are based on the data from (VHSS, 2017) 13 July 2017 for the 3,500 TEUs vessel and on the data on 03 August 2017 for the 1,700 TEU vessel (Hamburg Shipbrokers Association Contex Chartering Index) for a vessel type 3,500 TEUs, and 1,700 TEUs during a period of 12 months. This cost will be paid either the vessel is operational or not. The total ship charter rate for a period of one year is $3,081,695, and $2,694,065 for the 3,500 and 1,700 vessels respectively. The charter rate for the 250 vessel is assumed to be $1,200 per day, which means $438, 000 per year.

4.8 Port Time

Port time includes all the time a ship is spending in a port (Total Time). The port time is calculated starting from the time the ship arrives to the anchorage area until it leaves the port. The formula below presents how the Turn Round Time (TRT) is calculated as follow according to (Wardana, 2014):"

$$TRT = WT1 + PWT1 + BT + WT2 + PWT2$$

- *WT1 (First Waiting time) is the time a ship is waiting for the pilot in the anchorage area.*
- *PWT1 (First Pilot Working Time) is pilot service time from pick up the ship from anchorage until berthing area.*
- *BR (Berthing Time) is time when ship spends to loading and unloading container from and to ship. Those loading and unloading activity in port called stevedoring services. In this part, there are working time and not operation time. Operating time is total effective time spend to stevedoring activity, and not operating time is total times that waste from berth activity, such as waiting for truck, shifting, breaking time, accident, etc.*
- *WT2 (Second Waiting Time) is time when stevedoring activity finished and ship wait to handle by pilotage."*

The port time and waiting time is the same for all ports in this study, it is calculated assuming that the ship will be loading or offloading all the 3,500 TEUs used for the Hub & Spoke system while using two STSC. The crane productivity in all the ports is the same which is 17 TEU/Hour for one STSC. This number is subtracted from the average crane productivity of a crane in the WCA ports. For Rotterdam and Shanghai, the same average crane productivity is taking only for the simplicity of the model calculations, so the port time is 4.75 days and the waiting time is assumed to be two days.

For the port time of the DPCS using the 1,700 vessel the same assumption is used as the HSS, with only one STSC and with the same average crane productivity. The port time is 4.17 days, the waiting time is also two days. The port time for the 250 vessel is 1 day and the waiting time is also 1 day.

Chapter 5: Ports and Countries in West & Central Africa

This chapter is divided in three parts; the first part will give a small description of the container market in the WCA region. The second part will give a specific insight of the economy and the annual container market of each country in the WCA region. The third part will describe the main features of each port that help in determining other characteristics used in order to choose a specific port as a Hub and Spoke port such as market share, cargo flow…. etc**.**

5.1 Port Characteristics:

The table below presents the specifications of the major ports in the WCA region; ports that would be chosen should at least fulfill the requirements to handle the 3,500 TEUs vessel characteristics for the Hub & Spoke system and the 1,700 TEUs for the DPCS. We can notice from the table that not all the ports in the region can hoist the container vessel 3,500 TEUs (12.5 meter draught), which we did decide to use for the calculations in this paper. Even though, many countries such as Senegal, Ivory Coast, Ghana, Togo, Cameroun and Nigeria are investing a lot of money and resources to expand their port infrastructures (Increasing Canal draught, quay sides and purchasing of new handling equipment's in order to hoist mega vessels. Which means that bigger ships would be deployed in the future to serve the WCA market.

Table 6: WCA Ports Characteristics

Ports Specifications						
Country	Ports	Theoretical capacity (KTEU)	Max Draught (m)	yard Capacity (ha)	Quay length (m)	Crane (units)
Senegal	Dakar	600-800	11.5	35	660	8
	Future port (Dakar)	1.500	15	NA	1150	NA
Ivory Coast	Abidjan	1.300	11.5	34	1000	7
	Abidjan (TC2)	1.500	18	37.5	1000	NA
	San Pedro	120	13.5	10	210	2
Togo	Lomé	350	11 to 12	12	500	4 STS+2 STS to come
	Lomé (quay 3)	500	15	30	450	4
	Lomé container terminal	2000	16 to 17	53	400	NA
Ghana	Tema	500	11.5	10	575	6
	Tema expansion project	NA	14 to 17	250	4000	NA
	Takoradi	NA	9	34.9	190	NA
Nigeria	Lagos (TINCAN- bolloré)	450	11.5	24	770	1 STS+ 5 mobile
	Lagos (TINCAN- Grimaldi)	220	10	90	440	NA
	Lagos (APAPA)	850	10.5	55	1005	1 STS+ 9 mobile
	Future (BADGARY)	NA	NA	100	7000	NA
Benin	Cotonou	220	13.5-15	20	600	4+4 to come
Cameroun	Douala	500	7	26	660	2 STS+ 9 mobile
Gabon	Libreville	120	11	15	475	2 mobile
Republic of Congo	Pointe Noire	450	12 to 15	31	530	2 STS+ 3 mobile
Angola	Luanda	520	10.5	17.8	536	3 mobile
	Lobito	200	10	NA	414	2 STS
Liberia	Monrovia	125	11	8	600	NA
Sierra Leone	Freetown	380	10	3.5	722	2 Mobile
Guinea	Conakry	200	10.5	20	270	2 Mobile
Guinea Bissau	Bissau	5	7.6	NA	260	2 Mobile
Equatorial Guinea	Malabo	NA	16	NA	400	1 Mobile Crane
Gambia	Banjul	NA	12 to 14	38	750	NA

Source: Own creation based on (MLTC/CATRAM, 2013)

Moreover, there are many factors affecting the decisions while considering choosing a port over another in the route scheduling or choosing it as a Hub and Spoke port in WCA. In chapter 3, we did mention about the location problem that would be considered in this paper. Furthermore, the ports that cannot be chosen when defining the ship routing due to geographical restrictions or lack of adequate infrastructures, can be considered in the future, then a development study should be carried in order to assess the feasibility and resources required of such developments.

5.2 West & Central Africa Region Container Market and Countries

This paper describes five main ports in the WCA region that are chosen based on total container throughput, port characteristics, Gross Domestic Product (GDP) growth per country and number of future investment on port infrastructures by governments and foreign investors. Table 7 gives a summary of the container market in the WCA region based on (MLTC/CATRAM, 2013) report. The full list of the WCA container market per port in TEU will be presented see (Appendix 5.1).

Table 7: West and Central African Container Market per Port in (TEU)

Country	Port	2006	2010	2011	2015	2016
Senegal	Dakar	375,000.00	349,200.00	415,592.00	504,648.00	529,748.00
Ivory Coast	Abidjan	507,100.00	530,000.00	546,419.00	793,119.00	860,969.00
	San Pedro	49,800.00	77,000.00	80,000.00	111,093.00	120,597.00
Togo	Lomé	215,900.00	339,900.00	350,000.00	522,631.00	577,732.00
Ghana	Takoradi	51,000.00	53,000.00	57,000.00	74,292.00	79,379.00
	Tema	420,300.00	590,100.00	756,889.00	821,786.00	878,063.00
Benin	Cotonou	140,500.00	305,000.00	337,758.00	507,958.00	562,514.00
Nigeria	Apapa + Tin Can	587,600.00	1,120,000.00	1,413,276.00	1,883,206.00	2,023,325.00
	Onne	65,000.00	90,800.00	97,556.00	129,994.00	139,666.00
Pointe Noire	Pointe Noire	122,600.00	355,600.00	422,800.00	648,334.00	713,176.00
Angola	Luanda	377,200.00	583,300.00	631,247.00	865,822.00	936,992.00

Source: (MLTC/CATRAM, 2013)

5.2.1 Ivory Coast

In 2015, the country total container traffic was about 904,212 TEUs. The economy of Ivory Coast is mainly dependent on agricultural products; the country is the world's largest producer and exporter of cocoa, cashew nuts and palm oil (Worldbank, 2017). The economy dependency mainly on agricultural products and mineral resources (oil, diamond and gold) make it very sensitive when price of these commodities fluctuates (Worldbank, 2017). The country is seeking to develop its maritime transport sector, this started by extending its two main ports: Abidjan and San Pedro (Worldbank, 2017). The Abidjan port is the lung of Ivory Coast economy and a gateway to landlocked countries in the north (Worldbank, 2017).

5.2.2 Togo

The country economy also depends on agricultural products such as: Cocoa, coffee and cotton, which are the major resources of revenue for Togo, including also phosphate and clinker (worldbank, 2017). Since 2010, Togo government is making major investments in infrastructures, and especially in the maritime sector by investing in the port of Lomé to become a Hub and Spoke port in the WCA region (Worldbank, 2017). The new Lome Container Terminal (LTC) is the first fully automated container terminal in WCA (Rogers, 2017). The total cargo traffic registered in 2015 was about 15,413,487 million tons especially in the port of Lomé, which is the main major port in Togo (Ledy, 2016).

5.2.3 Ghana

Ghana's economy is considered amongst the strongest in West Africa (WA), with a population of 23 million people. Ghana registered a total container throughput of about 896,078 TEUs in 2015. The country is enjoying its position as the first producer of

Cocoa in the world (NationMaster, 2017). Natural resources and agriculture accounts for one quarter of GDP and 50% for services (NationMaster, 2017). Ghana's economy enjoys an economic boom after oil was discovered in 2010 and was expected to boost the economy but was stopped by the oil prices crisis (NationMaster, 2017).

5.2.4 Nigeria

In 2015, the total container traffic handled in Nigerian reached 2,013,100 TEUs. Nigeria is the 12th largest producer of oil in the world and one of the richest oil countries in Africa (GECF, 2016). Its economy is defined as a mixed economy that depends mainly in oil which accounts mainly for 35% of GDP and 90 % of the country total export (OPEC, 2017); and on a strong communication, transport, financial and legal sectors. Nigeria has a number of abundant natural resources that are still unexploited (OPEC, 2017).

5.2.5 Benin

As most of the WCA countries its economy depends mainly on agriculture and especially on the production of cotton (NationMaster, 2017). Which represents 25% of GDP, and plays as a major driver of the economic growth of the country in line with transportation (Worldbank, 2017). Especially its unique port (Port of Cotonou) and its geographical position as a trade gateway to landlocked neighboring countries (Mali and Niger). The total container throughput in 2015 reached 507,958 TEUs.

5.2.6 Senegal

The economy of Senegal relies on donations from different international agencies and foreign direct investments (NationMaster, 2017). Its main industries are mining, fishing, production of artificial fertilizers production and tourism (NationMaster, 2017). In the last decades, Senegal started many exploration projects for oil and iron ore in its soil (Komnenic, 2014). The maritime sector is also in decline due to congestion in the port of Dakar operated by DPW, which have played a big role as a transshipment port since many years. The total container throughput in 2015 handled by all ports reached 504,648 TEUs.

5.2.7. Congo Republic

The main driver of the Congo Republic economy is the oil industry, which account for 65% of the GDP. It also represents 92% of total exports of the country, followed by the mineral extractions, forestry and agriculture. The country total container traffic was about 648,334 TEUs in 2015. The country main trade partners are: China, France and Australia. Pointe Noire and Brazzaville are the two major port cities. The country economy was always affected by the political instability resulting in many civil wars, since its independence in 1960 (BBC, 2017).

5.2.8. Other countries in the WAC region:

Gabon

The country total container market accounted about 197,998 TEUs in 2014 (worldbank, 2017). Its economy also depends mainly on oil and manganese (Worldbank, 2017). Gabon is the fifth largest producer of oil in Africa. The oil industry accounts for 80% of country exports. Since 2013 the economy is in decline due to the low oil prices (Worldbank, 2017).

Equatorial Guinea

As most of the WA countries the country economy depends mainly on hydrocarbons (oil and gas). The country economy is in decline after the drop of oil prices. The country is now focusing on diversifying its economy by investing revenues from oil to industrial and agricultural projects (Worldbank, 2017).

Angola

The total container traffic in 2014 was about 1,000,000 TEUs (worldbank, 2017). Angolan economy depends mostly on oil exports which accounted for 97% of total exports in the last 10 years, followed by diamond as the second largest product exported (Worldbank, 2017).

Cameroun

Cameroun population is about 23.3 million people (Worldbank, 2017). The country is divided into two regions: Anglophone and francophone. The country economy is mainly dependent in oil, gas, other minerals and agricultural products (Worldbank, 2017). The container market accounted about 367,332 TEUs in total container traffic in 2014 (worldbank, 2017). Furthermore, Angola has two main commercial ports which are: Luanda, and Lobito.

Liberia

Liberia economy was devastated by the civil war from 1990 to early 2000 (Indexmundi, 2017). Liberia is a poor country that relies mainly on foreign aid and donations from rich countries (Indexmundi, 2017). The country revenues are engendered mainly from the extraction of iron ore, diamonds and gold. The country economy stagnates since two years, because of the drop of the price of commodities. Furthermore, the Ebola virus (Indexmundi, 2017). Liberia total container throughput was about 93,620 TEUs in 2015 (MLTC/CATRAM, 2013).

Gambia

Gambia is the smallest country in Africa, with a population of 2 Million people (Worldbank, 2017). Its economy is also small and relies mainly on tourism and agriculture. The economy also was hit as Liberia by the Ebola virus and harvest in 2014. The country plays a major role as a transit hub in the region (Worldbank, 2017).

Sierra Leone

Sierra Leone container traffic have reached 106,381 TEUs in 2015 (MLTC/CATRAM, 2013). The country is facing the same economic situation as its neighboring countries (Liberia and Gambia), due to low commodity prices and the impact of the Ebola virus. The country was always affected by civil wars in Liberia (The Commonwealth, 2017). The country soil base is very rich with diamond, gold, bauxite and iron ore (The Commonwealth, 2017). Moreover, the majority of the productions of diamond mainly leaves the country illegally (The Commonwealth, 2017).

Guinea

Guinea also known as Guinea-Conakry has a population of 12.9 million people (Indexmundi, 2017). Guinea has the world largest reserves of bauxite and iron ore (Indexmundi, 2017). These mineral products are the country main exports with diamond (Indexmundi, 2017). The country was also hit by the Ebola virus and the low commodity prices that slowed the country economy in 2014 and 2015 (Indexmundi, 2017).

Guinea-Bissau

Guinea-Bissau is one of the poorest countries in Africa. The country economy relies on international aid, agriculture (especially, the cashew exports which accounts for 80% of total exports) and fishing (Indexmundi, 2017). The country has a rich unexploited soil which in the future may help to prompt the country economy and development (Indexmundi, 2017).

Niger

Niger is a landlocked country and it is the second least developed country in the world according to United Nations (UN) rating 2016 (Indexmundi, 2017). The country economy relies on live stocks, agriculture, uranium and oil. Agriculture accounts 25 % of the country's GDP. The country soil is also very rich in mineral resources which may sustain economy growth in the future (Indexmundi, 2017).

Mali

Mali is also a landlocked country that is considered among the poorest countries in the world, and depends on foreign aid and donations (Indexmundi, 2017). Its economy depends mainly on agriculture and gold as a source of revenues (Indexmundi, 2017)**.**

Burkina Faso

Burkina Faso is a country that has similar characteristics as Mali and Niger with their dependence on mineral resources and agriculture (Indexmundi, 2017). Burkina Faso is a poor country that depends mainly on gold and cotton as country main exports (Indexmundi, 2017).

5.3 Ports in West and Central Africa

Abidjan

The port of Abidjan is the biggest port in Ivory Coast with a total seaborne traffic of 27,734,640 tons (portabidjan, 2017). Bolloré Africa Logistics (BAL) (60%) and APM Terminals (40%) operate the Abidjan Container Terminal (Portoverview, 2017). Furthermore, the port has a total quay length of 1,000 meters, 11.5 meter of draught, and a yard capacity of 36 hectares in which 20,000 TEUs can be stored (MLTC/CATRAM, 2013). The yearly container throughput was about 793 119 TEUs in 2015 (MLTC/CATRAM, 2013).

San Pedro

The port of San Pedro is the second largest port in Ivory Coast after the port of Abidjan in terms of total cargo tonnage, and one of the important infrastructures of the country (Bolloré Ports, 2016). The port was mainly built to support the Southwestern region, meanwhile the port plays a major role for transit of goods dedicated to landlocked neighboring countries. The port handled 4 Million/Metric tons of cargo in 2015, in which 3.2 Million/Metric tons are for transshipment goods (Bolloré Ports, 2016). The ports have a multi-purpose terminal for the export of palm oil, containers and Roll-On Roll-Off (RORO); the break-bulk terminal mainly dedicated to cacao, rice, lumber and fertilizers exports the main country resources (PASP, 2014).

Lomé

The port is situated in the southwest of the city, the port handles more than 80% of the country's trade. Furthermore, it is the only port in the WCA region that can hoist mega vessels (E-class vessels), with a 14 meters' draught (Togo-port, 2012). The port also serves as transit gateway to landlocked neighboring countries such as Burkina Faso, Mali and Niger (FinancialAfrik, 2016). The SE2M container terminal is operated by BAL (Portoverview, 2013). Furthermore, the new container terminal 'Lomé Container Terminal' (LCT) is partly owned (70%) by MSC (PatersonSimons, 2015). MSC will use the new Terminal planned to start operations this year as a transshipment hub for its activities while serving the WA market (TOGO, 2016). The new terminal has a capacity estimated to 1.5 Million TEUs, and will be able to hoist mega vessel up to 14,000 TEUs and with a maximum draught of 15.5 meters (TIL, 2012). The port handled a total of 522,631 TEUs in 2015 (MLTC/CATRAM, 2013).

Takoradi

The port of Takoradi is the second largest port in Ghana after the port of Tema. The port is operated by a special entity Ghana Ports and Harbors Authority (GPHA) (Portoverview, 2014). The port is more specialized in bulk and oil after its commercialization in 2007, but also a large amount of containerized goods are handled in the port, specially that the port is served by major shipping line like Maersk, MSC and BAL (GPHA, 2016).The container terminal has a maximum draught of 10 meters and quayside length of 225 meters (Portoverview, 2014). The port recorded a total container throughput of 74,292 TEUs in 2015 (MLTC/CATRAM, 2013).

Tema

The port of Tema is the largest port in Ghana and is also operated by GPHA (GPHA, 2016). The port is situated in the eastern coast of the country. The port receives more than 1650 calls per year (GPHA, 2016). Tema handles 85% of Ghana's international trade (GPHA, 2016). The current situation of the port is bad because of the port draught only 9 meters, the design also plays a negative role as the port was first designated for conventional traffic and not for containers as long as the lack of yard space (GPHA, 2016). The port handled a total container traffic of 821,786 TEUs in 2015 (MLTC/CATRAM, 2013).

Lagos (Appapa)

The port is located in the West of the capital Lagos; it is the largest and busiest port in Nigeria. The port is an entity of the Lagos Port Authority (LPA) (NPA, 2014). The port container terminal is operated since 2005 by APM Terminals (Worldportsource, 2017). The port is the biggest port in Nigeria and handles a number of other commodities such as containers, oil, cement and wheat (Worldportsource, 2017). The container terminal contains six berths with a draught of 10.5 meter and a total quay length of 950 meters. Furthermore, it has a capacity of 19.5 thousands TEUs (Worldportsource, 2017). The port total traffic including the traffic of TIN-CAN container terminal reached 1,883,206 TEUs in 2015 (MLTC/CATRAM, 2013).

Lagos (Tin-Can)

The Tin-Can terminal is also an entity of the LPA. BAL operates the container terminal since 2009 (Worldportsource, 2017).While the RORO terminal is operated by Grimaldi Group (Worldportsource, 2017). The container terminal has a draught of 11.5 meters and quay length of 750 meters (Worldportsource, 2017).

Cotonou

The port of Cotonou is a major port serving the WCA region. Since 2010, BAL operates the container terminal. The terminal has a draught of 13.5 meters and a quay length of 650 meters (MLTC/CATRAM, 2013). The port main exports are agricultural products (cotton, cashews and kapok) (Worldportsource, 2017). The port contains a free zone that plays as a trade harbor for the landlocked countries in the Central Saharan Africa (Burkina Faso, Niger and Mali) (Worldportsource, 2017). The port is known as an automotive center, importing huge amounts of European branded cars for the region. The port has registered a total traffic of 507,514 TEUs in 2015 (MLTC/CATRAM, 2013).

Dakar

The port of Dakar is the third largest port in West Africa after the port of Abidjan and port of Lagos. DPW operates the container terminal since 2006, with a quay length of 700m and a draught of 12 - 13 meters (Portdakar, 2017). The annual traffic throughput of the port exceeds 504,640 TEUs in 2015 (MLTC/CATRAM, 2013). The port served for many years as a hub for the WCA region due to its strategic position at the entry of the WA coast (MLTC/CATRAM, 2013). However, since many years now its position is declining because of congestion problems and lack of space in the port (MLTC/CATRAM, 2013). An extension of the port is planned to be complete by 2020 (MLTC/CATRAM, 2013).

Conakry

The port of Conakry is situated in the economic capital Conakry. BAL also operates the container terminal (Portoverview, 2017). The terminal contains two berths with 10.5 and 13 meters' draught respectively, and a total quay length of 600 meters (Port conakry, 2017). The container terminal registered a total traffic of 216,845 TEUs handled in 2015 (MLTC/CATRAM, 2013).

Douala

The port of Douala is situated in the heart of the Gulf of Guinea. The container terminal capacity is too low with only 5,000 TEUs (Port Authority of Douala, 2017). The draught is a major constraint for the port with only 9 meters, which make it very restricted to be visited by mega vessels (Port Authority of Douala, 2017). The container throughput registered in 2015 was about 519,577 TEUs (MLTC/CATRAM, 2013).

Libreville (Owendo)

The port of Libreville is the biggest port in Gabon. Furthermore, BAL operates the Owendo container terminal jointly with the OPRAG a local governmental Authority

(Portoverview, 2017). The container terminal has a maximum draught of 11 meters and a quay length of 475 meters, with an annual capacity of 250 000 TEUs (Bolloré Ports, 2017).

Pointe Noire

The port Autonome of Pointe Noire plays a major role for serving the WA region, especially that the majority of the traffic handled in the port is transshipment to neighbor countries like Gabon, Angola and Democratic Republic of Congo (Port Autonome de Pointe-Noire, 2017). In 2015, the port handled a total traffic of 571,860 TEUs, in which 390,030 TEUs were transshipment, and only 181,030 TEU were domestic and for transit to landlocked countries (Port Autonome de Pointe-Noire, 2017). The port has a draught of 15 meters and a quay length of 800 meters, which enables the port to become a true transshipment hub in Central Africa in the near future (Bolloré Ports, 2017). APM Terminals and BAL operate the container terminal jointly**.**

Malabo

The port of Malabo is situated in the Bioko Island. The port has a maximum draught of 16 meters, which make it one of the deepest ports in the WCA region and a quay length of 400 m (African Business Magazine, 2014). The port can handle mega vessels, which makes it a serious candidate to be a transshipment hub in the WCA region (African Business Magazine, 2014). The main international maritime links to the port are Douala and Spain.

Luanda

The port of Luanda is Angola main seaport and second busiest port (Worldportsource, 2017). The port registered a total container traffic of 865,822 TEUs in 2015 (MLTC/CATRAM, 2013). The main exports from the port are hydrocarbons and diamonds, and the main imports are construction products. Furthermore, the port has four terminals. Sogester a joint venture between APM Terminals and a local Angolan company operates the container terminal (Portoverview, 2017). The terminal has a quay length of 545 meters and a depth of 9.5 meters (MLTC/CATRAM, 2013).

Monrovia

The port of Monrovia is the main commercial port of Liberia, it is considered as a small port compared to its neighbor ports (Conakry and Dakar). The port registered a total container traffic of 93,620 TEUs in 2015 (MLTC/CATRAM, 2013). Furthermore, the port has a quay length of 600 meters and a draught that can reach 11 meters (MLTC/CATRAM, 2013). The container terminal was constructed and is operated by APM terminals for a concession period of 25 years (Portoverview, 2017).

Freetown

The port of Freetown is the largest and main commercial port in Sierra Leone. The economy of Sierra Leone depends mainly on the port. The port total container traffic was about 106,381 TEUs in 2015 (MLTC/CATRAM, 2013). The port is situated in the in the Sierra Leone River, which is considered as one the largest deep water harbors in the world (Koopmann, 2017). BAL is operating the container terminal, with a concession of 25 years starting from 2011 (Portoverview, 2017). The port has maximum draught of 10 meters, a quay length of 722 meters, and a yard capacity of 3.5 hectares (MLTC/CATRAM, 2013).

Banjul

The port of Banjul is the main sea port in Gambia, and a gateway for the local economy, and also to the neighboring landlocked countries (Styles, 2016). The port handles almost 90 % of the country foreign trade (Styles, 2016). In 2011, the port handled a total container traffic of about 13,440 TEUs (Styles, 2016).The Gambia Ports Authority (GPA) operates the port. Moreover, the port has a quay length of 750 meters and a draught of 12-14 meters (Portoverview, 2017).

Bissau

The port of Bissau is the main commercial port in Guinea-Bissau (Styles (b), 2017). Bissau is a general cargo port located in the Geba River. The port has poor infrastructures, equipment's and also capacity (Styles (b), 2017). The port has a draught of only 7.5 meters and a quay length of 260 meters (Styles (b), 2017).

In this chapter we gave a description of the WCA ports specifications (Quay length, maximum draught, yard capacity, etc.). These descriptions of each port with the location problem are necessary, especially to determine the candidate ports that will be chosen as Hub & Spoke ports in the WCA. Furthermore, a container market analysis for every country in the WCA region is also given to help understand and have a general overview of the WCA countries. Moreover, a detailed description (overview) of each port in the WCA coast is given, including the port total throughput and important information's of the ports.

All these descriptions of the WCA market, countries and ports will be used to determine the Hub & Spoke ports. After choosing the ports, the shipping routes and cargo allocation will be determined, then the result comparison of the two systems (Hub & Spoke and Direct Port Calls) will be given in Chapter 6.

Chapter 6: Results and Analysis

This chapter will present the results from the model calculations for the HSS, which are divided into three parts: the port aggregation, ship routing and cargo allocation. Furthermore, for the DPCS the ship routing and cargo allocation using excel spreadsheet for the best possible routes will be presented.
Moreover, the profit, cost and revenue of each system will also be given. The calculations are done using the models explained in chapter 3 and using data from chapter 4. Furthermore, a comparison of the two systems (direct calls and Hub & Spoke) from Europe – Asia to WCA will also be given.

6.1 Results:

The port aggregation method is divided into four parts. The first part using an aggregation of six Hub & Spoke ports for the Europe – WCA route. Furthermore, the second part is done using aggregation with only five Hub & Spoke ports Europe – WCA route. We then compare the two results using six Hub & Spoke ports with five Hub & Spoke ports to assess which of the two results engenders higher profits (more optimal in terms of profit maximization. The third part use the same aggregation of six Hub & Spoke ports but this time for the Asia – WCA route. Similarly, to the previous route, in the fourth part, we use only five Hub & Spoke ports for the same route Asia – WCA route. A comparison is also done to compare the two aggregations of the Asia – WCA route.

In the fifth part, we study the possible direct routes for serving the WCA region via Europe and then via Asia. Using direct ship routing from Rotterdam and Shanghai, the best routes are then chosen to maximize the profit using excel spreadsheet model for the calculations. Finally, in the sixth part we give a comparison of the two systems.

A qualitative analysis of the ports characteristics is done to assess which ports are eligible to be chosen as Hub & Spoke ports and which ones can hoist the 3,500 TEUs vessel chosen to serve those ports. This analysis is done based on the port characteristics given in Chapter 5 Section 5.1. The ports characteristics that will be determined as criteria's to be fulfilled by the ports in order to be elected are: the draught, the quay length, yard capacity, yearly throughput of the port, and the maximum vessel size. The table below presents the fulfillment criteria's used:

Table 8: Ports criteria fulfillment

	Draught	Quay length	Yard Capacity	Maximum Vessel Size	Container throughput
Dakar	x	x	x	x	x
Banjul	x				
Bissau					
Conakry			x		
Freetown					
Monrovia		x			
San Pedro		x			
Abidjan	x	x	x	x	x
Takoradi			x		
Tema		x		x	x
Lome	x	x	x	x	x
Cotonou	x	x	x	x	
Lagos		x	x	x	x
Douala		x	x		
Malabo	x	x		x	
Libreville		x			
Pointe Noire	x	x	x	x	x
Luanda		x		x	x

Source: Own creation

From the table above, we can see that only five ports can fulfill all the five criteria's in order to be considered as a Hub & Spoke port. The Cotonou port will be used to assess the first part using five hub ports in the region because it fulfills all the criteria. Then it will be deleted in the second part using only four Hub & Spoke ports in the region because the Cotonou port is too close to the port of Lomé. Moreover, it does not fulfill all the criteria's to be considered as a hub port. In reality it is not possible that two ports are considered as Hub ports in the same geographical areas and in the same time served by the same ship.

To sum up the five ports to be considered as Hub and Spoke ports in the WCA region are: Dakar, Abidjan, Lomé, Cotonou, and Pointe Noire.

6.2 Hub & Spoke Scenario:

Figure 4: Hub & Spoke Ports Scenario (Port Aggregation)

Source: (MLTC/CATRAM, 2013)

The figure above represents the Hub & Spoke scenario for serving the WCA region from Europe and Asia. The feasibility of serving the WCA Region through that system will be answered in this chapter.

6.2.1 Six Hub & Spoke ports: Europe – WCA:

Port Aggregation:

Figure 5: Port aggregation of Five Hub & Spoke Ports in WCA

Source: Own Creation

Those ports are chosen based on their annual container throughput and on the port specifications fulfillment criteria's (see Table Chapter 5), which would allow the 3,500 TEUs vessel to visit all the selected ports. Furthermore, a constraint is made, that the chosen ports as hub ports must have more than 100 nautical miles' distance between each other. In other words, ports next to each other cannot be visited by the 3,500 TEUs vessel as long as the distance is less than 100 nautical miles.

After the ports are aggregated, the vessel route is designed so that the vessel visits each port once or twice depending on the amount of the imports trade volume between Europe and WCA countries. From trade figures (see Appendix 4.2) we can notice that imports are greater than exports from WCA countries and Europe. So, the ports can be visited only once to offload the supply coming from Europe. Exports from WCA countries are mainly transported in bulk as long as the majority of the cargo types are hydrocarbons (oil or minerals). Furthermore, the ports are visited only once in order to reduce the voyage costs (especially the port dues that would be charged twice) based on number of port visits.

Table 9: Origin Destination Demand Matrix of Six Hub Ports (in TEU)

		Europe	Senegal	Ivory Coast	Togo	Benin	Congo	
		Rotterdam	Dakar	Abidjan	Lome	Cotonou	Pointe Noire	Supply
Europe	Rotterdam	0	54,335	124,920	70,556	19,613	54,818	324,242
Senegal	Dakar	70,023	0	2,906	869	375	576	74,749
Ivory Coast	Abidjan	155,706	1,796	0	1,727	1,064	109	160,401
Togo	Lome	162,964	616	1,428	0	1,716	137	166,860
Benin	Cotonou	606,146	6,218	19,900	4,312	0	343	636,919
Congo	Pointe Noire	80,791	561	2,508	91	126	0	84,077
	Demand	1,075,630	63,526	151,662	77,555	22,893	55,983	1,447,248

Source: Own creation

The table 9 explains how the cargo allocation is made adding the demand from the small ports not selected as transshipment hub to the demand of the ports or countries chosen as hub ports, the trade between ports in the same country is not included, it is considered to be zero. The demand is horizontal from Rotterdam to Rotterdam is considered to be 0, and from Rotterdam to Cotonou is about 606,146 TEU per year. The total demand at the bottom indicates the total container coming from Rotterdam to all the other ports (yearly demand). Furthermore, the table 9 is determined by adding the demand of small ports to the hub ports, for instance we add the demand from the port of Dakar we add to it the demand from Gambia, Guinea Bissau, Guinea Conakry and Mali (see appendix 4.2), the same thing we do it for the port of Abidjan, we add the demand to it the total yearly demand from Liberia, Sierra Leone and Burkina Faso.
Moreover, for Togo (Lomé) we add to it the demand from Ghana and Niger. Then for Cotonou we add the demand from Nigeria, Equatorial Guinea and Cameroun. For the last port (Pointe Noire) we add to it the demand from Angola and Gabon.
The port of Cotonou has a large supply because it aggregates the port of Lagos (Nigeria) which represents the highest demand from Rotterdam to Lagos which is about 548,026 TEUs.

Ship routing:

After defining the O/D matrix the second method is applied which is the ship routing. This is done using excel spreadsheet, by simulating the model many times trying various possible routes, that through connecting the demand and supply from and to selected ports. The most profitable routes are then selected. The containers transported by the first route are then subtracted from the original yearly demand matrix. This process is done several times until the whole demand is satisfied or the route does not generate any profit. The Table below presents the routes used in the simulations in the model.

The first route is chosen following a round trip system the vessel should visit all the ports regarding if there is supply or not. The second route is chosen while assessing the highest demand from to each port, some ports are visited only once because the demand is too low, and the cost of visiting those ports twice are higher than the revenue. the routes are determined to satisfy the whole demand but when the revenue is lower than the costs the port is not visited at all.

Table 10: Ship Routing of Six Ports

ROUTE	PORTS										
	RTM	**DKR**	**ABJ**	**LOM**	**CTN**	**PN**	**PN**	**CTN**	**LOM**	**ABJ**	**DKR**	**RTM**
1	1	2	3	4	5	6	6	7	8	9	10	1
2	1	2						3	4	5	6	1
3	1	2	3						4	5	6	1
4	1	2		3	4				5	6		1

Source: Own Creation

RTM : Rotterdam **DKR** : Dakar **ABJ** :Abidjan
LOM : Lomé **CTN** : Cotonou **PN** : Pointe Noire

Example of a route in a round trip:

RTM – DKR – ABJ – LOM – CTN – PN – CTN – LOM - ABJ – DKR - RTM

Feeder Network Routes:

The feeder network is used to connect the smaller ports in the region, those ports that weren't selected as transshipment hubs. This routes are served by a small container vessel with a capacity of 250 TEUs. The ship allocation to each route are selected based on the cargo flow and ports restrictions. The feeder routes selected are as follow:

1. DKR – BJL – BSU – CKRY - DKR
2. ABJ – MNV – FRTW - ABJ
3. LOM – TM – LOM
4. CTN – LGS – MLB – DLA - CTN
5. PN – LBV – LDA – PN

BJL: Banjul **TM:** Tema **TKD:** Takoradi
BSU: Bissau **LGS:** Cotonou **MLB:** Malabo
CKRY: Conakry **DLA:** Douala **LBV:** Libreville
LDA: Luanda

Table 11 will give the model results for the feeder routes serving the Hub ports selected from the aggregation:

Table 11: Feeder Routes Results for Five Hubs in WCA

	Total
Containers / year	**24 118,00**
Distance (NM)	**5 130,00**
Vessels / year	**5**
Port visits / year	**504**
Revenue / year	**28 085 000,00**
Ship Cost ($) / year	2 190 000,00
Fuel Cost ($) / year	2 608 994,00
Port Dues ($) / year	2 520 000,00
Handling Cost ($) / year	9 261 312,00
Total Cost ($) / year	**16 580 306,00**
Profit ($) / year	**11 504 694,00**

Source: Own creation

The calculations are done using the same model calculations as for the hub ports, using the same table for determining the O/D matrix for each route (see appendix 4.2). The routes for the feeder network are defined following a round trip network. So, for each route we determine a origin demand matrix, the routes are as follow:

1. DKR- BJL- BSU- CKRY-DKR
2. ABJ-MNRV-FRTW-ABJ
3. LOM-TEMA-LOM
4. CTN-LGS-MLB-DLA-CTN
5. PN-LBV-LDA-PN

The port dues are different for each route as the vessel visits different ports.

Cargo Allocation and Model Results:

Table 12 Parameter of Objective Function

Revenue	$ 1500	Per TEU transported
Ship Charter Cost	$ 3 025 120	Per ship in a year
Fuel Cost	$ 30.5	Per nautical mile
Port Dues	$ 13 992	Per port visited
Handling Cost	$ 192	Per container handled

Source: Own creation

The port dues in each objective function is different as the vessel visits more or less ports for each system. Furthermore, the port dues for each port are not the same.
Model results are summarized in the table below, the calculations are done using excel solver using the objective function presented in chapter 3.1 and using data and formulas from chapter 4. Here below the model results:

Table 13: Model Result of Six Hub & Spoke ports

	Route 1	**Route 2**	**Route 3**	**Route 4**	**Total**
Containers / year	**97 505,00**	**235 662,00**	**406 525,00**	**707 566,00**	**1 447 248,00**
Distance (NM)	**10 018,00**	**8 170,00**	**8 186,00**	**6 797,00**	**33 171,00**
Vessels / year	**1**	**2**	**7**	**15**	**25,00**
Port visits / year	**60**	**168**	**168**	**490**	**886,00**
Revenue / year	**146 257 500,00**	**353 493 000,00**	**609 787 500,00**	**1 061 349 000,00**	**2 170 887 000,00**
Ship Cost ($) / year	3 025 120,00	6 050 240,00	21 175 840,00	45 376 800,00	75 628 000,00
Fuel Cost ($) / year	3 666 588,00	5 980 440,00	20 972 532,00	37 315 530,00	67 935 090,00
Port Dues ($) / year	839 520,00	2 350 656,00	2 350 656,00	6 856 080,00	12 396 912,00
Handling Cost ($) / year	37 441 920,00	90 494 208,00	156 105 600,00	271 705 344,00	555 747 072,00
Total Cost ($) / year	**44 973 148,00**	**104 875 544,00**	**200 604 628,00**	**361 253 754,00**	**711 707 074,00**
Profit ($) / year	**101 284 352,00**	**248 617 456,00**	**409 182 872,00**	**700 095 246,00**	**1 459 179 926,00**

Source: Own creation

The table above shows, that the total number of containers that should be transported are 1,447,258 TEUs**.** Thus, represents 100% of the total demand. The handling cost is obtained by multiplying the number of containers handled in each port by the handling cost in each of these ports. The revenue is also obtained by multiplying the number of container based on the ocean freight rate for each destination of each of the routes chosen by the model. Furthermore, the fuel cost is calculated based on the distance travelled between ports (See Appendix) by each vessel for each route multiplied by the number of vessels, times the number of trips per year, times the fuel cost per each nautical mile which is 33.5 $. The charter time cost is based on the number of the total vessels serving each route, multiplied by the charter cost rate per year.

The port dues are based on the number of port visits by each vessel for each route multiplied by a fixed amount for each port visit, the port dues are fixed for all the ports as explained in the main assumptions for simplification of the model calculations. The total profit is US $ 1.7 Billion/Dollar for a yearly service period.

6.2.2 Four Hub & Spoke ports: Europe – WCA

Port Aggregation:

Figure 6: Port Aggregation of Four Hub & Spoke Ports in WCA

Source: Own Creation

The explanation of the port aggregation of four hub ports is the same as the five hub ports, the only difference is that the Cotonou is eliminated, and is not considered anymore as a Hub port in the WCA region (see explanation port aggregation of six hub ports). The container flow of port Cotonou is now handled through the port of Lome, and a new feeder network will be determined to serve the new hub ports.

Table 14: Origin Destination Demand Matrix of Five hub ports in WCA

		Europe	Senegal	vory Coast	Togo	Congo	
		Rotterdam	Dakar	Abidjan	Lome	ointe Noire	Supply
Europe	Rotterdam	0	54 335	142 148	70 352	54 818	321 653
Senegal	Dakar	70 873	0	2 906	881	576	75 236
vory Coast	Abidjan	180 598	1 902	0	1 954	134	184 589
Togo	Lome	689 106	5 637	17 543	0	258	712 544
Congo	Pointe Noire	124 713	1 651	5 224	3 568	0	135 157
	Demand	1 065 291	63 526	167 821	76 756	55 786	1 429 179

Source: Own Creation

Table 14 indicates the O/D matrix for five hub ports in the region. The demand is horizontal from Rotterdam to Rotterdam is considered to be 0, and from Rotterdam to Lome is about 689,106 TEU per year. The total demand at the bottom indicates the total container coming from Rotterdam to all the other ports (yearly demand). Furthermore, the table 14 is determined by adding the demand of small ports to the hub ports. This table container numbers are different from table one because the port aggregation is different. The port of Cotonou is not considered anymore, because its too close to the port of Lome. As mentioned in the assumptions (See chapter 3). The distance between two ports should be more than 100 NM.
For instance, the demand from the port of Dakar we add to it the demand from Gambia, Guinea Bissau, Guinea Conakry, Sierra Leone and Mali (see appendix 4.2), the same thing we do it for the port of Abidjan, we add the demand to it the total yearly demand from Liberia, Sierra Leone, and Burkina Faso.
Moreover, for Togo (Lomé) we add to it the demand from Nigeria, Benin, Ghana and Niger. For the last port (Pointe Noire) we add to it the demand from Cameroun, Equatorial Guinea, Angola and Gabon.

Ship Routing:

The ship routes are determined using the new O/D Matrix, then the new ship routes can be presented as the following:

Table 15: Ship Routing of Five Ports

ROUTE	PORTS									
	RTM	**DKR**	**ABJ**	**LOM**	**PN**	**PN**	**LOM**	**ABJ**	**DKR**	**RTM**
1	1	2	3	4	5	5	6	7	8	1
2	1		3	4	5	5	6	7	8	1
3	1	2	3	4			4	5	6	1
4	1		2							1

Source: Own Creation

An example is also given to explain the round trip, when the port visits all the ports:

- RTM – DKR – ABJ – LOM – PN – LOM – ABJ – DKR - RTM

The feeder network between the Hub & Spoke port is determined to satisfy the intra-trade between the ports as the ship route defined for the Hub and Spoke serve those ports only once and not twice. So, a feeder service is determined (for instance ABJ to DKR).

Feeder Network Routes:

The calculations for the feeder network are determined using the excel solver. The number of containers transported is determined using the solver, which choose the optimal routes. An O/D matrix is used for each route (see appendix 4.2). the port dues are different for each route as the vessel visits different ports.

1. DKR - BJL - BSU – CKRY – FRTW - DKR
2. ABJ – MNV - ABJ
3. LOM – TM – LGS – CTN - LOM
4. PN - LBV - DLA - MLB - LDA –PN

Feeder Network Results:

Table 16: Feeder Results for Four Hub Ports in WCA

	Total
Containers / year	**32 205,00**
Distance (NM)	**4 432,00**
Vessels / year	**5**
Port visits / year	**698**
Revenue / year	**48 307 500,00**
Ship Cost ($) / year	1 768 800,00
Fuel Cost ($) / year	3 533 687,50
Port Dues ($) / year	4 450 000,00
Handling Cost ($) / year	12 364 944,00
Total Cost ($) / year	**22 117 431,50**
Profit ($) / year	**26 190 068,50**

Source: Own Creation

Cargo Allocation and Model Results:

Table 17 Parameter of Objective Function

Revenue	$ 1500	Per TEU transported
Ship Charter Cost	$ 3 025 120	Per ship in a year
Fuel Cost	$ 30.5	Per nautical mile
Port Dues	$ 15 066	Per port visited
Handling Cost	$ 192	Per container handled

Source: Own creation

The port dues are different because the number of ports did decrease, but the average port dues may differ depending on the ports visited. Each ports has a different port dues than other ports.

Table 18: Model Result of Five Hub & Spoke ports

	Route 1	Route 3	Total
Containers / year	**135 157,00**	**1 303 020,00**	**1 438 177,00**
Distance (NM)	**9 878,00**	**8 186,00**	**18 064,00**
Vessels / year	**2,00**	**21,00**	**23,00**
Port visits / year	**72,00**	**1 764,00**	**1 836,00**
Revenue / year	**202 735 500,00**	**1 954 530 000,00**	**2 157 265 500,00**
Ship Cost ($) / year	6 050 240,00	63 527 520,00	**69 577 760,00**
Fuel Cost ($) / year	8 435 812,00	62 917 596,00	**71 353 408,00**
Port Dues ($) / year	1 084 752,00	26 576 424,00	**27 661 176,00**
Handling Cost ($) / year	51 900 288,00	500 359 680,00	**552 259 968,00**
Total Cost ($) / year	**67 471 092,00**	**653 381 220,00**	**720 852 312,00**
Profit ($) / year	**135 264 408,00**	**1 301 148 780,00**	**1 436 413 188,00**

Source: Own Creation

The table above represents the model calculations as for the six Hub & Spoke ports. The total of containers transported are 1,438,177 TEUs. The majority of the containers are transported via route 3. The total distance of the two routes is 18,064 nautical miles. Furthermore, the ship charter cost is about $ 69,577,760 for the 23 vessels deployed to serve those routes. The fuel cost is about $ 71,353,408 and the total port dues are about $ 21,461,922. The handling cost represents more than the half of the total costs by more than $ 258 Million/Dollar.

6.2.3 Comparison of Hub Network (Europe – WCA):

Table 19: Comparison Hub System with Five Ports Vs Hub with Four Ports in Europe – WCA route

	Hub 1 + Feeder 1	Hub 2 + Feeder 2
Containers / year	**1 471 376,00**	**1 470 382,00**
Distance (NM)	**38 301,00**	**22 496,00**
Vessels / year	**30,00**	**28,00**
Port visits / year	**1 390,00**	**2 534,00**
Revenue / year	**2 198 972 000,00**	**2 205 573 000,00**
Ship Cost ($) / year	77 818 000,00	71 346 560,00
Fuel Cost ($) / year	70 544 084,00	74 887 095,50
Port Dues ($) / year	14 916 912,00	32 111 176,00
Handling Cost ($) / year	565 008 384,00	564 624 912,00
Total Cost ($) / year	**728 287 380,00**	**742 969 743,50**
Profit ($) / year	**1 470 684 620,00**	**1 462 603 256,50**

Source: Own Creation

Two port aggregation methods are used using different number of ports. The first method with five ports and the second with only five ports. The results from the model calculations tables show several differences between the two models. The number of ports visited decreased and that affected the number of containers transported and also the routes. The number of vessels decreased by two vessels from the first aggregation to the second aggregation. The distance, travelled by the vessels also decreased. Furthermore, the profit decreased from $1,756,460,484.40 US/Dollar to 1,736,000,550. However, the port dues have doubled because, the number of ports visits increased. Another comparison that can be also made is the cost of transporting one TEU. It is calculated by dividing the total costs by the total number of containers transported, after the calculations of this cost, it shows that the cost for the first model with six ports is 286$/per one TEU transported and the cost for the second model with 5 ports is 292$ / TEU transported.

6.2.4 Six Hub & Spoke ports: in Asia – WCA

Port Aggregation:

Figure 7: Port Aggregation of Five Hub & Spoke ports in WCA

Pointe Noire
- Libreville
- Luanda

Cotonou
- Lagos
- Douala
- Malabo

Lome
- Tema
- Takoradi

Abidjan
- Monrovia
- San Pedro
- Freetown

Dakar
- Banjul
- Bissau
- Conakry

Source: Own Creation

Table 20: Origin Destination Demand Matrix of Six Hub Ports in WCA

		Asia	Congo	Benin	Togo	Ivory Coast	Senegal	
		Shanghai	Pointe Noire	Cotonou	Lome	Abidjan	Dakar	Supply
Europe	Shanghai	0	62 186	68 809	64 287	56 221	56 052	307 555
Congo	Pointe Noire	99 602	0	126	91	2 508	561	102 887
Benin	Cotonou	414 696	343	0	4 312	19 900	6 218	445 469
Togo	Lome	106 319	137	1 716	0	1 428	616	110 215
Ivory Coast	Abidjan	170 114	109	1 064	1 727	0	1 796	174 810
Senegal	Dakar	37 258	576	375	869	2 906	0	41 984
	Demand	827 989	63 351	72 090	71 285	82 962	65 242	1 182 919

Source: Own creation

The cargo allocation is mainly the same as for the Europe- WCA routes, the number of containers handled between the WCA ports are the same only the supply and demand coming and going to Asia is different.

Ship routing:

The routes are determined based on the solver results, after simulating the routes many times. The table below gives the possible routes for serving the Hub & Spoke ports in the WCA region:

Table 21: Ship Routing of Six Ports

ROUTE	**PORTS**											
	SGH	**PN**	**CTN**	**LOM**	**ABJ**	**DKR**	**DKR**	**ABJ**	**LOM**	**CTN**	**PN**	**SGH**
1	1	2	3	4	5	6	6	7	8	9	10	1
2	1	2	3		4	5	5					1
3	1		2		3			3		4		1
4	1		2			3	3			4		1

Source: Own Creation

SGH : Shanghai
LOM : Lomé
DKR : Dakar
CTN : Cotonou
ABJ :Abidjan
PN : Pointe Noire

Feeder Network Routes:

1. PN – LBV – LDA - PN
2. CTN – LGS – MLB – DLA - CTN
3. LOM – TM – LOM
4. ABJ – MNV – FRTW – ABJ
5. DKR – BJL – BSU – CKRY - DKR

The feeder routes model results are the same for Europe – WCA route using the same ports and cargo allocation.

Cargo Allocation & Model results:

Table 22: Parameter of Objective Function

Revenue	\$ 2 469	Per TEU transported
Ship Charter Cost	\$ 3 025 120	Per ship in a year
Fuel Cost	\$ 30.5	Per nautical mile
Port Dues	\$ 13 992	Per port visited
Handling Cost	\$ 192	Per container handled

Source: Own creation

Table 23: Model Result of Six Hub & Spoke ports for a Year Period

	Route 1	**Route 2**	**Route 4**	**Total**
Containers / year	**317 911,00**	**69 999,00**	**795 005,00**	**1 182 915,00**
Distance (NM)	**23 892,00**	**21 366,00**	**23 622,00**	**68 880,00**
Vessels / year	**2**	**4**	**42**	**48,00**
Port visits / year	**100**	**72**	**1 260,00**	**1 432,00**
Revenue / year	**784 922 259,00**	**172 827 531,00**	**1 962 867 345,00**	**2 920 617 135,00**
Ship Cost ($) / year	6 050 240,00	12 100 480,00	127 055 040,00	145 205 760,00
Fuel Cost ($) / year	7 287 060,00	15 639 912,00	151 298 910,00	174 225 882,00
Port Dues ($) / year	1 399 200,00	1 007 424,00	17 629 920,00	20 036 544,00
Handling Cost ($) / year	122 077 824,00	26 879 616,00	305 281 920,00	454 239 360,00
Total Cost ($) / year	**136 814 324,00**	**55 627 432,00**	**601 265 790,00**	**793 707 546,00**
Profit ($) / year	**648 107 935,00**	**117 200 099,00**	**1 361 601 555,00**	**2 126 909 589,00**

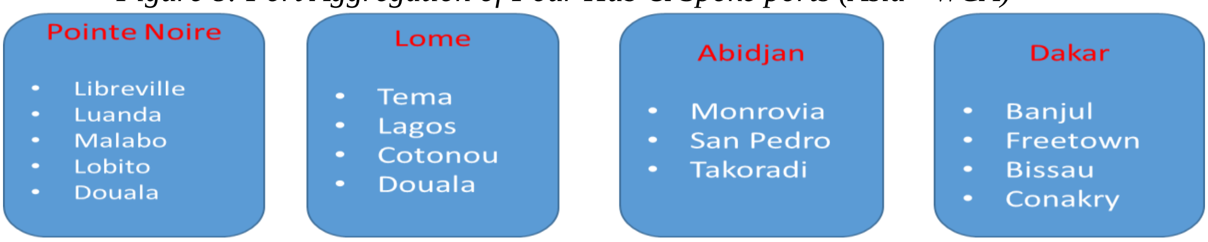
Source: Own creation

The table above represents the model calculations as for the Europe - WCA. The total containers transported are 1,182,915 TEUs, which represents 100 % of the total demand. Moreover, the total distance of the three routes is 68,880 nautical miles. Furthermore, the ship charter cost is about $ 145 Million/Dollar for a total of 48 vessels deployed to serve those routes. The fuel cost is about $ 174 Million/Dollar and the total port dues are about $ 16 Million/Dollar. The handling cost represents approximately the half of the total costs by more than $ 212 Million Dollar. The total profit represents $ 2.3 Billion/Dollar.

6.2.5 Five Hub & Spoke ports: Asia – WCA

Port Aggregation:

Figure 8: Port Aggregation of Four Hub & Spoke ports (Asia - WCA)



Source: Own Creation

Table 24: Origin Destination Demand Matrix of Five hub ports in WCA

		Asia	Congo	Togo	vory Coast	Senegal	
		Shanghai	**Pointe Noire**	**Lome**	**Abidjan**	**Dakar**	**Supply**
Asia	**Shanghai**	**0**	**62 382**	**64 894**	**56 518**	**56 052**	**239 846**
Congo	**Pointe Noire**	**165 719**	**0**	**3 568**	**5 224**	**1 651**	**176 163**
Togo	**Lome**	**428 974**	**258**	**0**	**17 543**	**5 637**	**452 412**
Ivory Coast	**Abidjan**	**196 037**	**134**	**1 954**	**0**	**1 902**	**200 028**
Senegal	**Dakar**	**37 302**	**576**	**881**	**54 335**	**0**	**93 095**
	Demand	**828 032**	**63 351**	**71 298**	**133 620**	**65 242**	**1 161 544**

Source: Own Creation

Ship routing:

Table 25: Ship Routing of Five Ports

ROUTE	**PORTS**									
	SGH	**PN**	**LOM**	**ABJ**	**DKR**	**DKR**	**ABJ**	**LOM**	**PN**	**SGH**
1	1	2	3	4	5	5	6	7	8	1
2	1		2	3			3		4	1
3	1		2	3	4	4	5			1
4	1			2			2	3		1

Source: Own Creation

Feeder Network Routes:

1. PN – LBV – DLA – MLB – LDA - PN
2. LOM – TM – LGS – CTN - LOM
3. ABJ – MNV – ABJ
4. DKR - BJL - BSU – CKRY – FRTW - DKR

For the feeder model results are the same as for the Europe – WCA route using only four ports in the WCA region.

Cargo Allocation & Model Results:

Table 26: Parameter of Objective Function

Revenue	$ 2 469	Per TEU transported
Ship Charter Cost	$ 3 025 120	Per ship in a year
Fuel Cost	$ 30.5	Per nautical mile
Port Dues	$ 15 066	Per port visited
Handling Cost	$ 192	Per container handled

Source: Own creation

Table 27: The Model Result of Five Hub & Spoke Ports:

	Route 1	Route 4	Total
Containers / year	**508 300,00**	**587 999,00**	**1 096 299,00**
Distance (NM)	**23 818,00**	**20 989,00**	**44 807,00**
Vessels / year	**14**	**28**	**42,00**
Port visits / year	**630**	**432**	**1 062,00**
Revenue / year	**1 254 992 700,00**	**1 451 769 531,00**	**2 706 762 231,00**
Ship Cost ($) / year	42 351 680,00	84 703 360,00	**127 055 040,00**
Fuel Cost ($) / year	50 851 430,00	107 547 636,00	**158 399 066,00**
Port Dues ($) / year	9 491 580,00	6 508 512,00	**16 000 092,00**
Handling Cost ($) / year	195 187 200,00	225 791 616,00	**420 978 816,00**
Total Cost ($) / year	**297 881 890,00**	**424 551 124,00**	**722 433 014,00**
Profit ($) / year	**957 110 810,00**	**1 027 218 407,00**	**1 984 329 217,00**

Source: Own creation

The table above represent the most optimal routes considered by the excel solver, the routes chosen are 2 and 4. The total number of containers transported are about 1,096,299 TEUs, which represents 94 % of the total demand. Moreover, the total distance is about 44,807 nautical miles compared to the first model with six ports. The number of vessels deployed to serve those two routes are only 42 vessels. Furthermore, the total profit exceeds 1.9 Billion/ Dollar.

6.2.6 Comparison of Hub Network (Asia – WCA):

Table 28: Comparison Hub System with Five Ports Vs Hub with Four Ports in Asia – WCA route

	Hub 1 + Feeder 1	Hub 2 + Feeder 2
Containers / year	**1 207 033,00**	**1 128 504,00**
Distance (NM)	**74 010,00**	**49 239,00**
Vessels / year	**53,00**	**47,00**
Port visits / year	**1 936,00**	**1 760,00**
Revenue / year	**2 948 702 135,00**	**2 755 069 731,00**
Ship Cost ($) / year	147 395 760,00	128 823 840,00
Fuel Cost ($) / year	176 834 876,00	161 932 753,50
Port Dues ($) / year	22 556 544,00	20 450 092,00
Handling Cost ($) / year	463 500 672,00	433 343 760,00
Total Cost ($) / year	**810 287 852,00**	**744 550 445,50**
Profit ($) / year	**2 138 414 283,00**	**2 010 519 285,50**

Source: Own creation

The Table above represents a comparison between the Hub and Spoke system for six and five hubs respectively for the Europe- WCA route. From the calculations tables we notice that 3 routes are selected for the six ports model and only two for the five port model. The total distance for the second model is shorter with about 49 239 nautical miles a difference of approximately more than 24 000 nautical miles, compared with the first model with six ports. The number of vessels deployed to serve those two routes are only 47 vessels compared to 53 for the previous model with 3 routes. Moreover, the transport cost of one TEU for the first model using six ports is 464 $/TEU, while for the second model with five ports is only 451$/TEU. The calculation of the transport cost for one TEU is the same as for the Europe – WCA route.

6.3 Direct Port Call Scenario:

Figure 9: Direct Call shipping

Source: (MLTC/CATRAM, 2013)

The figure above represents the scenario of serving the WCA region by direct calling system from Europe and Asia. This system is the one used by all shipping companies serving the region, only exception is MSC. This chapter will give the model calculation results, to assess whether these shipping companies should continue to serve the region using direct call system or switch to the Hub & Spoke system as MSC.

6.3.1 Direct port calls network: Europe - WCA

Direct 1: Europe – WCA

Ship Routing:

The routes below are chosen using the solver simulation of the most optimal routes.

1. Route 2: RTM – CNKRY – RTM
2. Route 3: RTM – DKR – BJL – BSU – FRTW - RTM

Table 29: Origin Destination Demand Matrix of Six Ports

		Europe	Senegal	Gambia	Guinea	Guinea	Sierra Leone	Supply
		Rotterdam	Dakar	Banjul	Bissau	Conakry	Freetown	Total
Europe	Rotterdam	0	70333	3118	1115	28005	7287	109857
Senegal	Dakar	55235	0	598	540	816	181	57370
Gambia	Banjul	993	281	0	4	38	10	1327
Guinea	Bissau	1216	442	4	0	0	0	1662
Guinea	Conakry	12579	352	0	0	0	10	12941
Sierra Leone	Freetown	850	1	15	0	0	0	866
	Demand	70873	1076	617	544	854	201	74166

Source: Own creation

Cargo Allocation & Model Results:

Table 30 Parameter of Objective Function

Revenue	$ 1500	Per TEU transported
Ship Charter Cost	$ 2 694 065	Per ship in a year
Fuel Cost	$ 30.5	Per nautical mile
Port Dues	$ 19 116 (route 2) $ 21 420 (route 3)	Per port visited
Handling Cost	$ 192	Per container handled

Source: Own creation

Table 31 The Model Result of Six Ports (Direct 1 Europe – WCA):

	Route 2	Route 3	Total
Containers / year	**20 796,00**	**162 357,00**	**183 153,00**
Distance (NM)	**6 030,00**	**6 382,00**	**12 412,00**
Vessels / year	**1**	**3**	**4,00**
Port visits / year	**54**	**306**	**360,00**
Revenue / year	**31 194 000,00**	**243 535 500,00**	**274 729 500,00**
Ship Cost ($) / year	2 469 065,00	7 407 195,00	9 876 260,00
Fuel Cost ($) / year	3 310 470,00	9 927 201,00	13 237 671,00
Port Dues ($) / year	1 032 264,00	6 554 520,00	7 586 784,00
Handling Cost ($) / year	7 985 664,00	62 345 088,00	70 330 752,00
Total Cost ($) / year	**14 797 463,00**	**86 234 004,00**	**101 031 467,00**
Profit ($) / year	**16 396 537,00**	**157 301 496,00**	**173 698 033,00**

Source: Own creation

Direct 2: Europe – WCA

Ship Routing:

The routes below are chosen using the solver simulation of the most optimal routes.

1. Route 3: RTM – ABJ - MNRV – RTM
2. Route 4: RTM – MNRV – TM – RTM

Table 32 Origin Destination Demand Matrix of Four Ports

		Europe	Liberia	Ivory Coast	Ghana	
		Rotterdam	Monrovia	Abidjan	Tema	Supply
Europe	Rotterdam	0	24244	144031	125603	293877
Liberia	Monrovia	24244	0	253	308	24805
Ivory Coast	Abidjan	130611	253	0	3389	134254
Ghana	Tema	133275	308	989	0	134572
	Demand	288130	24805	145273	129300	587508

Source: Own creation

Model Results:

The objective function parameters are the same as the previous ones, the only difference is that the port dues for route 3 are $ 23 484 / port visit, while for route 4 are $ 25 980 / port visit.

Table 33 The Model Result of Four Ports (Direct 2 Europe – WCA):

	Route 3	Route 4	Total
Containers / year	**272 772,00**	**30 949,00**	**303 721,00**
Distance (NM)	**7 474,00**	**7 950,00**	**15 424,00**
Vessels / year	**5**	**7**	**12,00**
Port visits / year	**300**	**196**	**496,00**
Revenue / year	**409 158 000,00**	**46 423 500,00**	**455 581 500,00**
Ship Cost ($) / year	12 345 325,00	17 283 455,00	29 628 780,00
Fuel Cost ($) / year	17 096 775,00	23 762 550,00	40 859 325,00
Port Dues ($) / year	7 045 200,00	5 092 080,00	12 137 280,00
Handling Cost ($) / year	104 744 448,00	11 884 416,00	116 628 864,00
Total Cost ($) / year	**141 231 748,00**	**58 022 501,00**	**199 254 249,00**
Profit ($) / year	**267 926 252,00**	**-11 599 001,00**	**256 327 251,00**

Source: Own creation

Direct 3: Europe – WCA

Ship Routing:

The routes below are chosen using the solver simulation of the most optimal routes.

1. Route 3: RTM – LM – CTN – LGS - RTM
2. Route 4: LGS – CTN – RTM – LGS

Table 34: Origin Destination Demand Matrix of Four Ports

		Europe	Togo	Benin	Nigeria	
		Rotterdam	Lome	Cotonou	Lagos	Supply
Europe	Rotterdam	0	75298	19427	290856	385582
Togo	Lome	29689	0	395	209	30293
Benin	Cotonou	14198	812	0	87	15097
Nigeria	Lagos	548026	24	84	0	548134
	Demand	591913	76134	19906	291152	979105

Source: Own creation

Model Results:

The objective function parameters are the same as the previous ones, the only difference is that the port dues for route 3 are $ 17 362 / port visit, while for route 4 are $ 16 486 / port visit.

Table 35: The Model Result of Four Ports (Direct 3 Europe – WCA):

	Route 3	Route 4	Total
Containers / year	**452 162,00**	**496 648,00**	**948 810,00**
Distance (NM)	**8 362,00**	**8 345,00**	**16 707,00**
Vessels / year	**17**	**8**	**25,00**
Port visits / year	**1190**	**336**	**1 526,00**
Revenue / year	**678 243 000,00**	**744 972 000,00**	**1 423 215 000,00**
Ship Cost ($) / year	41 974 105,00	19 752 520,00	61 726 625,00
Fuel Cost ($) / year	60 699 758,00	28 506 520,00	89 206 278,00
Port Dues ($) / year	20 660 780,00	5 539 296,00	26 200 076,00
Handling Cost ($) / year	173 630 208,00	190 712 832,00	364 343 040,00
Total Cost ($) / year	**296 964 851,00**	**244 511 168,00**	**541 476 019,00**
Profit ($) / year	**381 278 149,00**	**500 460 832,00**	**881 738 981,00**

Source: Own creation

Direct 4: Europe – WCA

Ship Routing:

The routes below are chosen using the solver simulation of the most optimal routes.

1. Route 1: RTM – LDA - RTM
2. Route 2: RTM – DLA – MLB – LBV – PN – RTM
3. Route 4: RTM – LDA – LBV – MLB - RTM

Table 36: Origin Destination Demand Matrix of Six Ports

		Europe	Cameroun	EG	Gabon	Congo	Angola	
		Rotterdam	Douala	Malabo	Libreville	Pointe Noire	Luanda	Supply
Europe	Rotterdam	0	60256	14841	17860	46725	21207	160888
Camaeroun	Douala	29081	0	298	156	50	204	708
EG	Malabo	14841	298	0	0	146	0	444
Gabon	Libreville	17860	156	81	0	7689	0	7926
Congo	Pointe Noire	41764	109	146	7689	0	4031	11975
Angola	Luanda	21168	20	0	0	403	0	424
	Demand	124713	60838	15367	25704	55014	25442	182365

Source: Own creation

Model Results:

The objective function parameters are the same as the previous for route 1 direct call, the only difference is that the port dues for route 1 are $ 16 127 / port visit, for route 2 are $ 17 330, while for route 4 are $ 28 294 / port visit.

Table 37 The Model Result of Six Ports (Direct 4 Europe – WCA):

	Route 1	Route 2	Route 4	Total
Containers / year	**39 679,00**	**144 727,00**	**122 670,00**	**307 076,00**
Distance (NM)	**9 954,00**	**21 366,00**	**10 334,00**	**41 654,00**
Vessels / year	**1**	**3**	**4**	**8,00**
Port visits / year	**36**	**146**	**193,00**	**375,00**
Revenue / year	**59 518 500,00**	**217 090 500,00**	**184 005 000,00**	**460 614 000,00**
Ship Cost ($) / year	2 469 065,00	7 407 195,00	9 876 260,00	**19 752 520,00**
Fuel Cost ($) / year	3 643 164,00	23 459 868,00	15 128 976,00	**42 232 008,00**
Port Dues ($) / year	580 572,00	2 586 768,00	5 476 870,00	**8 644 210,00**
Handling Cost ($) / year	15 236 736,00	55 575 168,00	47 105 280,00	**117 917 184,00**
Total Cost ($) / year	**21 929 537,00**	**89 028 999,00**	**77 587 386,00**	**188 545 922,00**
Profit ($) / year	**37 588 963,00**	**128 061 501,00**	**106 417 614,00**	**272 068 078,00**

Source: Own creation

6.3.2 Direct port calls network: Asia – WCA

Direct 1: Asia – WCA

Ship Routing:

The routes below are also chosen using the solver simulation of the most optimal routes.

1. Route 1: SGH – LDA – PN – MLB – LBV – PN - SGH
2. Route 2: SGH – PN – LBV – DLA – SGH

Table 38 Origin Destination Demand Matrix of Six Ports

		Asia	Angola	Congo	Gabon	EG	Cameroun	
		Shanghai	Luanda	Pointe-Noire	Libreville	Malabo	Douala	Supply
Asia	Shanghai	0	39 456	54 094	104 614	15 735	63 952	277 851
Angola	Luanda	52 481	0	403	0	0	20	424
Congo	Pointe-Noire	43 951	4 031	0	7 689	146	109	11 975
Gabon	Libreville	19 817	0	7 689	0	81	156	7 926
EG	Malabo	15 735	0	146	0	0	298	444
Camaeroun	Douala	50 382	204	50	156	298	0	708
	Demand	182 367	43 691	62 382	112 459	16 260	64 535	299 328

Source: Own creation

Model results:

Table 39 Parameter of Objective Function

Revenue	$ 2 469	Per TEU transported
Ship Charter Cost	$ 2 694 065	Per ship in a year
Fuel Cost	$ 30.5	Per nautical mile
Port Dues	$ 21 288 (route 1) $ 19 907 (route 2)	Per port visited
Handling Cost	$ 192	Per container handled

Source: Own creation

Table 40 The Model Result of Six Ports (Direct 1 Asia – WCA):

	Route 1	**Route 2**	**Total**
Containers / year	**155 201,00**	**275 400,00**	**430 601,00**
Distance (NM)	**20 274,00**	**20 214,00**	**40 488,00**
Vessels / year	**1**	**27**	**28,00**
Port visits / year	**48**	**810**	**858,00**
Revenue / year	**383 191 269,00**	**679 962 600,00**	**1 063 153 869,00**
Ship Cost ($) / year	2 469 065,00	66 664 755,00	69 133 820,00
Fuel Cost ($) / year	3 710 142,00	99 877 374,00	103 587 516,00
Port Dues ($) / year	1 021 824,00	16 124 670,00	17 146 494,00
Handling Cost ($) / year	59 597 184,00	105 753 600,00	165 350 784,00
Total Cost ($) / year	**66 798 215,00**	**288 420 399,00**	**355 218 614,00**
Profit ($) / year	**316 393 054,00**	**391 542 201,00**	**707 935 255,00**

Source: Own creation

Direct 2: Asia – WCA

Ship Routing:

The routes below are also chosen using the solver simulation of the most optimal routes.

1. Route 2: SGH – CTN - SGH
2. Route 3: SGH – CTN – LOM – LGS – SGH

Table 41 Origin Destination Demand Matrix of Four Ports

		Asia	Nigeria	Benin	Togo	
		Shanghai	Lagos	Cotonou	Lome	Supply
Asia	Shanghai	0	279 994	68 586	68 620	417 200
Nigeria	Lagos	338 647	0	84	24	338 754
Benin	Cotonou	9 932	87	0	812	10 831
Togo	Lome	19 909	209	395	0	20 513
	Demand	368 488	280 290	69 065	69 455	787 298

Source: Own creation

Model Results:

The objective function parameters are the same as the previous route (Direct 1 Asia – WCA), the only difference is that the port dues for route 2 are $ 9 485 / port visit, while for route 4 they are $ 17 362 / port visit.

Table 42 The Model Result of Four Ports (Direct 2 Asia - WCA):

	Route 2	**Route 3**	**Total**
Containers / year	**357 000,00**	**398 954,00**	**755 954,00**
Distance (NM)	**20 526,00**	**20 721,00**	**41 247,00**
Vessels / year	**35**	**6**	**41,00**
Port visits / year	**48**	**180**	**228,00**
Revenue / year	**881 433 000,00**	**985 017 426,00**	**1 866 450 426,00**
Ship Cost ($) / year	86 417 275,00	14 814 390,00	101 231 665,00
Fuel Cost ($) / year	131 469 030,00	22 751 658,00	154 220 688,00
Port Dues ($) / year	455 280,00	3 125 160,00	3 580 440,00
Handling Cost ($) / year	137 088 000,00	153 198 336,00	290 286 336,00
Total Cost ($) / year	**355 429 585,00**	**193 889 544,00**	**549 319 129,00**
Profit ($) / year	**526 003 415,00**	**791 127 882,00**	**1 317 131 297,00**

Source: Own creation

Direct 3: Asia – WCA

Ship Routing:

The route below is chosen using the solver simulation of the most optimal routes.

1. Route 2: SGH – TM – ABJ – MNRV - SGH

Table 43 Origin Destination Demand Matrix of Four Ports

		Asia	Ghana	Ivory Coast	Liberia	
		Shanghai	Tema	Abidjan	Monrovia	Supply
Asia	Shanghai	0	181 779	64 371	104 614	350 765
Ghana	Tema	104 614	0	3 389	308	108 311
Ivory Coast	Abidjan	65 456	989	0	989	67 435
Liberia	Monrovia	86 409	3 389	308	0	90 107
	Demand	256 480	186 158	68 069	105 911	616 617

Source: Own creation

Model Results:

The objective function parameters are the same as the previous route (Direct 1 Asia – WCA), the only difference is that the port dues for route 2 are $ 22 028 / port visit.

Table 44 The Model Result of Six Ports (Direct 3 Asia – WCA):

	Route 2	**Total**
Containers / year	**615 143,00**	**615 143,00**
Distance (NM)	**21 627,00**	**21 627,00**
Vessels / year	**35**	**35,00**
Port visits / year	**1050**	**1 050,00**
Revenue / year	**1 518 788 067,00**	**1 518 788 067,00**
Ship Cost ($) / year	86 417 275,00	86 417 275,00
Fuel Cost ($) / year	138 520 935,00	138 520 935,00
Port Dues ($) / year	23 129 400,00	23 129 400,00
Handling Cost ($) / year	236 214 912,00	236 214 912,00
Total Cost ($) / year	**484 282 522,00**	**484 282 522,00**
Profit ($) / year	**1 034 505 545,00**	**1 034 505 545,00**

Source: Own creation

Direct 4: Asia – WCA

Ship Routing:

The route below is chosen using the solver simulation of the most optimal routes.

1. Route 4: SGH – FRTW – CNKRY – BSU – BJL – DKR - SGH

Table 45: Origin Destination Demand Matrix of Six Ports

		Asia	Sierra Leone	Guinea	Guinea	Gambia	Senegal	
		Shanghai	Freetown	Conakry	Bissau	Banjul	Dakar	Supply
Asia	Shanghai	0	10 240	33 700	2 494	8 518	63 772	118 724
Sierra Leone	Freetown	44	0	10	0	10	181	201
Guinea	Conakry	11 857	0	0	0	38	816	854
Guinea	Bissau	2 679	0	0	0	4	540	544
Gambia	Banjul	1 743	15	0	4	0	598	617
Senegal	Dakar	20 979	1	352	442	281	0	1 076
	Demand	37 302	10 255	34 062	2 940	8 851	65 907	122 016

Source: Own creation

Model Results:

The objective function parameters are the same as the previous route (Direct 1 Asia – WCA), the only difference is that the port dues for route 4 are $ 20 958 / port visit.

Table 46 The Model Result of Six Ports (Direct 4 Asia – WCA):

	Route 4	**Total**
Containers / year	**159 312,00**	**159 312,00**
Distance (NM)	**22 248,00**	**22 248,00**
Vessels / year	**12**	**12,00**
Port visits / year	**504**	**504,00**
Revenue / year	**393 341 328,00**	**393 341 328,00**
Ship Cost ($) / year	29 628 780,00	29 628 780,00
Fuel Cost ($) / year	48 856 608,00	48 856 608,00
Port Dues ($) / year	10 562 832,00	10 562 832,00
Handling Cost ($) / year	61 175 808,00	61 175 808,00
Total Cost ($) / year	**150 224 028,00**	**150 224 028,00**
Profit ($) / year	**243 117 300,00**	**243 117 300,00**

Source: Own creation

6.4 Comparison Hub & Spoke Vs Direct Port Calling systems:

6.4.1 Europe – WCA Route:

Table 47: Comparison of the Hub & Spoke System vs. Direct call System (EUR- WCA)

	Hub 1 + Feeder 1	**Hub 2 + Feeder 2**	**Direct EUR-WCA**
Containers / year	**1 471 376,00**	**1 470 382,00**	**1 742 760,00**
Distance (NM)	**38 301,00**	**22 496,00**	**86 197,00**
Vessels / year	**30,00**	**28,00**	**49,00**
Port visits / year	**1 390,00**	**2 534,00**	**2 757,00**
Revenue / year	**2 198 972 000,00**	**2 205 573 000,00**	**2 614 140 000,00**
Ship Cost ($) / year	77 818 000,00	71 346 560,00	120 984 185,00
Fuel Cost ($) / year	70 544 084,00	74 887 095,50	185 535 282,00
Port Dues ($) / year	14 916 912,00	32 111 176,00	54 568 350,00
Handling Cost ($) / year	565 008 384,00	564 624 912,00	669 219 840,00
Total Cost ($) / year	**728 287 380,00**	**742 969 743,50**	**1 030 307 657,00**
Profit ($) / year	**1 470 684 620,00**	**1 462 603 256,50**	**1 583 832 343,00**

Source: Own creation

The Table 47 gather the results of the calculations for the route Europe – WCA, the results of the first method using aggregation with five ports plus its feeder network. All the costs and revenues are added together to make a comparison between those results and the ones from the aggregation using four ports and its feeder network. Moreover, with the DPC system to see which system is better for serving the region, that in order to answer the research question. The numbers of containers are different because the excel solver which determine the routes. Sometimes not all demand can be satisfied, as mentioned in the assumptions if a route produces more costs than revenue, it should be excluded or deleted by the shipping line.

From the table above we can notice that the WCA region should be served through the direct calling system from Europe. The total profit of the direct call system is higher and satisfies the demand of more ports than the Hub & Spoke system. Even if it uses more vessels and that the distances traveled are 3 times greater than for the Hub & Spoke system.

6.4.2 Asia – WCA Route:

Table 48: Comparison of the Hub & Spoke System vs. Direct call System (ASIA- WCA)

	Hub 1 + Feeder 1	**Hub 2 + Feeder 2**	**Direct ASIA-WCA**
Containers / year	**1 207 033,00**	**1 128 504,00**	**1 961 010,00**
Distance (NM)	**74 010,00**	**49 239,00**	**125 610,00**
Vessels / year	**53,00**	**47,00**	**116,00**
Port visits / year	**1 936,00**	**1 760,00**	**2 640,00**
Revenue / year	**2 948 702 135,00**	**2 755 069 731,00**	**4 841 733 690,00**
Ship Cost ($) / year	147 395 760,00	128 823 840,00	286 411 540,00
Fuel Cost ($) / year	176 834 876,00	161 932 753,50	445 185 747,00
Port Dues ($) / year	22 556 544,00	20 450 092,00	54 419 166,00
Handling Cost ($) / year	463 500 672,00	433 343 760,00	753 027 840,00
Total Cost ($) / year	**810 287 852,00**	**744 550 445,50**	**1 539 044 293,00**
Profit ($) / year	**2 138 414 283,00**	**2 010 519 285,50**	**3 302 689 397,00**

Source: Own creation

The table 48 also gather all the results for the Asia – WCA route. Using the same methods as for the Europe – WCA route.
From the table above we can also notice that the WCA region should be served through the direct calling system from Asia. The total profit of the direct call system is greater by almost 60% and satisfies the demand of more ports than the Hub & Spoke system. Furthermore, the number of containers transported is higher by almost 50 % than the Hub & Spoke System. However, the direct call system uses two times more vessels and travels more distances than the Hub & Spoke system, this is justified by the number of containers transported are greater.

Chapter 7 Conclusion and Recommendation

7.1. Conclusion

This paper discussed the best way to serve the WCA region from Europe and Asia for governments and shipping lines and that through using Hub & Spoke System or Direct Port Calling. During many years, the WCA region was served through direct call shipping network, that due to ports restrictions in the region and especially the draught and inadequate handling equipment's. In recent years several investments are made by local government, shipping lines and big terminal operators, especially for the construction of new ports in the region, or through the extension of existing ones.

Before setting any model, we first assessed the ports in the region, their market share, container throughput, specifications, and the role they play in the local and regional economy. Furthermore, the economy of each country to have a macroeconomic overview of the region. Second, based on the origin demand matrix of the container flow between all the ports in the region and Europe – Asia. Moreover, based on the distance matrices between those ports a model is formulated.

The main purpose of this thesis is to maximize the profit for each system using the most optimal routes. An objective function is then formulated based on each route profit, which is then added to other profit from other routes for each system. The model calculations are done using data such as: container trade flows between ports, the fuel price, ship charter rate, port dues and handling fees for each port visited by the chosen ship, the ship itself, the appropriate speed. Those data are then used to calculate the fuel consumption per nautical mile for each vessel, the number of trips per year, the yearly charter rate etc.

In order to obtain the profit, all the costs (fuel costs, handling costs, port dues and ship charter costs) engendered during a whole year period are subtracted from the yearly revenue. This revenue is obtained by multiplying the number of containers transported by each route by an ocean freight rate determined based on the destination.

The container throughput for each port and the container market in each country, in addition to the ports characteristics described in chapter five are used in chapter six to select the appropriate ports to become Hub ports in the region, these informations are used as fulfillment criteria's for the selection of the Hub ports. From the fulfillment criteria assessment five ports are chosen as hub ports. Furthermore, the port aggregation is done using the location problem and a qualitative analysis. The aggregation is used to capture all the demand from smallest and nearest ports around the hub port, the transport is done using a feeder network. Moreover, the shipping routes and cargo allocation are done using an excel solver, this is done simulating the model several times until the most profitable routes, that satisfy the maximum demand for all the ports are determined.

The results from the aggregation of five hub ports for the Europe – WCA route using the model gives the highest profit more than the four hub ports aggregation. Four routes are determined by the solver that satisfies 100 % of the total demand using 30 vessels (Hub and feeder networks). The total profit gained from those routes is about more than $1.46 Billion/ Dollar, plus $11.5 Million/ Dollar profit from the feeder network. Rotterdam port is visited by all the routes as long as the majority of the container flow is coming and going from it.

The same method is used for the Asia – WCA Route, the aggregation using five port in the WCA region, gives also the highest profits, compared to the four hub ports aggregation. Two routes are selected by the excel solver using 48 vessels, with a profit obtained of $ 2.1 Billion/ Dollar.

The model is again applied to the direct calling system for Europe – WCA and Asia – WCA routes. The results for the Europe - WCA show 9 different routes using a total of 49 vessels, with a total profit reaching more than $1.58 Billion/ Dollar, which is greater than the profit using the Hub & spoke system for the same route.

Furthermore, the results for the Asia – WCA gives 6 possible routes using a total of 116 vessels, and engendering a total profit of $ 3.3 Billion/Dollar. Compared to the Hub & Spoke System for the same route, this profit represents almost 50 % of the Hub system.

At the end of this paper a comparison of the two systems is done, showing that the Direct Calling System is more profitable than the Hub & Spoke System. We conclude that the shipping lines should continue to serve the WCA region using direct calls.

7.2 Recommendation:

In this part we represent the recommendations which are divided in two parts. The first part is a recommendation giving to shipping lines, and the second is related to further researches that should be done using the same model or other models but with more updated and accurate data.

Shipping lines before making any investment in the WCA region, they should negotiate attractive tariffs especially for the port dues, tugging and mooring, these costs are too high in the majority of the ports in the region. Designing a route and visiting a port in WCA two times can be very expensive. Another point is the congestion inside and outside the ports, this point is not considered in this paper, but this is a serious problem in all African ports, especially outside and in the surroundings of the ports. The infrastructures especially road and rail are too poor, the queues for entering or leaving the port can take sometimes too long hour of waiting times, and that may affect the productivity and efficiency of the ports.

For further researches, updated data should be available and accurate, the difficulty while doing any research and especially a thesis for the WCA is the scarcity or the non-existence of data and information's. Even if some information's are found, these data may be outdated or not reliable. This research assumed that the ocean freight rate between WCA ports is the same as for Europe route and the same for the Asia route, this is due to the non-existence of adequate freight rate information's between WCA ports. Furthermore, the waiting time and port is the same.

The data of container flow are calculated using a conversion method from trade values in US $ to TEUs, accurate data can be used to recalculate the model and specially the aggregation. Concerning the ship routing and cargo allocation could be done using a mathematical programming model as used by the majority of researchers for more accurate results.

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List of Appendices:

Appendix 4.1:
Distance (Nautical Miles)

Port	Rotterdam	Le Havre	Tangier	Dakar	Banjul	Bissau	Conakry	Freetown	Monrovia	Abidjan	Takoradi	Tema	Lomé	Cotonou	Lagos	Douala	Malabo	Libreville	Pointe Noire	Luanda	Durban	Singapore	Shanghai
Rotterdam	0	247	1342	2582	2667	2818	3015	3070	3264	3730	3861	3973	4059	4112	4171	4550	4481	4545	4791	4977	6944	8288	10525
Le Havre	247	0	1137	2377	2462	2613	2810	2865	3059	3525	3656	3768	3854	3907	3966	4345	4276	4340	4586	4772	6739	8083	10320
Tangier	1342	1137	0	1479	1564	1715	1915	1970	2164	2634	2765	2870	2956	3016	3075	3446	3385	3441	3691	3876	5854	6955	9192
Dakar	2582	2377	1479	0	96	256	450	505	699	1166	1297	1409	1495	1548	1607	1987	1918	1982	2228	2414	4385	8425	10662
Banjul	2667	2462	1564	96	0	215	409	464	658	1125	1256	1368	1454	1507	1566	1940	1876	1940	2186	2369	4342	8510	10747
Bissau	2818	2613	1715	256	215	0	364	419	613	1080	1211	1323	1409	1462	1521	1900	1831	1896	2141	2324	4297	8661	10898
Conakry	3015	2810	1915	450	409	364	0	69	297	764	895	1007	1093	1146	1205	1580	1511	1575	1821	2007	3985	8796	10884
Freetown	3070	2865	1970	505	464	419	69	0	251	718	849	961	1047	1100	1159	1533	1464	1528	1779	1962	3943	8754	10842
Monrovia	3264	3059	2164	699	658	613	297	251	0	470	601	713	799	852	911	1285	1216	1280	1528	1714	3720	8531	10619
Abidjan	3730	3525	2634	1166	1125	1080	764	718	470	0	155	259	345	398	457	830	769	850	1118	1345	3467	8278	10366
Takoradi	3861	3656	2765	1297	1256	1211	895	849	601	155	0	116	203	261	320	701	637	722	997	1218	3385	8196	10284
Tema	3973	3768	2870	1409	1368	1323	1007	961	713	259	116	0	90	154	213	600	542	647	964	1176	3380	8191	10279
Lomé	4059	3854	2956	1495	1454	1409	1093	1047	799	345	203	90	0	70	134	533	476	595	908	1146	3379	8190	10278
Cotonou	4112	3907	3016	1548	1507	1462	1146	1100	852	398	261	154	70	0	62	481	420	551	875	1115	3364	8175	10263
Lagos	4171	3966	3075	1607	1566	1521	1205	1159	911	457	320	213	134	62	0	439	377	513	846	1089	3355	8166	10254
Douala	4550	4345	3446	1987	1940	1900	1580	1533	1285	830	701	600	533	481	439	0	65	237	616	838	3165	7976	10064
Malabo	4481	4276	3385	1918	1876	1831	1511	1464	1216	769	637	542	476	420	377	65	0	225	601	846	3149	7960	10048
Libreville	4545	4340	3441	1982	1940	1896	1575	1528	1280	850	722	647	595	551	513	237	225	0	415	651	2952	7763	9851
Pointe Noire	4791	4586	3691	2228	2186	2141	1821	1779	1528	1118	997	964	908	875	846	616	601	415	0	245	2599	7410	9498
Luanda	4977	4772	3876	2414	2369	2324	2007	1962	1714	1345	1218	1176	1146	1115	1089	838	846	651	245	0	2391	7202	9290
Durban	6944	6739	5854	4385	4342	4297	3985	3943	3720	3467	3385	3380	3379	3364	3355	3165	3149	2952	2599	2391	0	4867	7015
Singapore	8288	8083	6955	8425	8510	8661	8796	8754	8531	8278	8196	8191	8190	8175	8166	7976	7960	7763	7410	7202	4867	0	2237
Shanghai	10525	10320	9192	10662	10747	10898	10884	10842	10619	10366	10284	10279	10278	10263	10254	10064	10048	9851	9498	9290	7015	2237	0

Appendix 4.2:
Container Flow/Demand (TEU)

	Europe&Centrale Asia	East Asia&Pacific	South Asia	Senegal	Ivory Coast	Togo	Ghana	Nigeria	Benin	Cameroun	Congo	Gabon	EG	Liberia	Sierra L	G-Conakry	Gambia	G-Bissau	Mali	Burkina F	Niger	Angola
Europe&Centrale Asia	0	21,562,395	2,372,580	53,260	124,667	69,797	125,603	290,856	19,427	60,256	46,725	17,860	14,841	24,244	7,287	28,005	3,118	1,115	17,073	19,363	5,501	21,207
East Asia&Pacific	20,607,058	0	1,824,642	43,322	42,295	52,835	125,053	169,420	57,653	49,582	48,799	19,579	13,832	100,903	8,165	22,723	6,919	677	6,107	4,441	4,206	34,383
South Asia	1,946,207	1,751,994	0	11,655	13,673	10,692	56,726	110,574	10,933	14,370	5,295	916	1,903	3,711	2,075	10,977	1,599	1,816	2,688	3,963	886	5,073
Senegal	47,918	4,657	7,911	0	1,630	624	184	732	312	790	567	144	51	1	181	816	598	540	0	0	0	26
Ivory cost	120,272	39,189	7,699	1,744	0	1,716	3,389	23,822	987	1,307	95	334	1,320	253	335	26	94	47	0	0	0	50
Togo	10,000	8,885	2,045	261	439	0	245	209	395	99	50	46	11	1	12	32	6	235	0	0	0	1
Ghana	133,275	70,447	15,963	355	989	759	0	4,673	1,321	201	83	104	136	308	264	338	44	734	0	0	0	34
Nigeria	548,026	208,610	130,037	4,873	16,412	24	2,337	0	84	987	129	2	129	13	22	34	1	5	0	0	0	4
Benin	14,198	4,097	5,834	254	772	812	247	87	0	27	18	79	22	7	5	24	1	24	0	0	0	116
Cameroun	29,081	36,570	13,813	885	1,396	3,466	82	844	117	0	50	156	298	71	1	0	2	24	0	0	0	204
Congo	41,764	41,764	2,187	390	2,124	44	323	11	35	109	0	7,689	146	0	1	6	1	8	0	4	0	4,031
Gabon	17,860	19,579	238	144	334	46	104	2	79	156	7,689	0	81	0	0	1	0	8	0	15	4	0
Equatorial Guinea	14,841	13,832	1,903	206	1,320	11	136	129	22	298	146	0	0	0	0	15	0	0	0	1	1	0
liberia	24,244	100,903	3,711	51	253	10	308	13	7	71	0	0	0	0	1	18	0	0	0	0	0	0
Sierra Leone	850	42	2	1	0	0	33	0	70	0	0	0	0	1	0	0	15	0	0	0	0	0
Guinea-Conakry	12,579	7,517	4,340	352	74	13	5,602	9	39	6	1	15	0	18	28	0	0	0	0	0	0	0
Gambia	993	1,206	537	281	1,154	9	9	1	0	0	0	0	0	0	10	38	0	4	0	0	0	0
Guinéa- Bissau	1,216	862	1,816	442	47	235	734	5	24	24	8	0	0	0	0	0	4	0	0	0	0	0
Mali	7,317	6,107	2,304	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burkina Fasso	10,339	14,239	4,329	0	0	0	0	0	0	0	15	1	68	0	0	0	0	0	0	0	0	0
Niger	19,688	8,408	572	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0
Angola	21,168	31,314	4,520	26	50	1	34	18	12	20	403	0	0	0	0	0	0	0	0	0	0	0

Appendix 4.3:
Containerization Ratio (%)

	Europe&Centrale Asia	East Asia&Pacific	South Asia	Senegal	Ivory Coast	Togo	Ghana	Nigeria	Benin	Cameroun	Congo	Gabon	EG	Liberia	Sierra L	G-Conakry	Gambia	G-Bissau	Mali	Burkina F	Niger	Angola
Europe&Centrale Asia	0	0.95	0.9	1	0.9	1	1	0.6	1	1	0.7	0.4	0.3	1	0.8	1	1	0.55	0.7	0.7	0.7	0.1
East Asia&Pacific	0.95	0	0.5	1	0.9	1	1	0.5	1	1	0.7	0.4	0.3	1	1	1	1	0.55	0.7	0.7	0.7	0.1
South Asia	0.9	0.5	0	1	0.9	1	1	0.6	1	1	0.7	0.4	0.3	1	1	1	1	0.55	0.7	0.7	0.8	0.1
Senegal	1	1	1	0	0.5	0.98	0.98	0.9	0.98	1	1	0.7	1	0.5	0.5	0.55	0.45	0.55	0	0	0	0.1
Ivory cost	0.9	0.9	0.9	0.5	0	0.45	0.45	0.85	0.9	1	1	1	1	0.5	0.5	0.65	0.99	0.95	0	0	0	0.1
Togo	1	1	1	0.98	0.45	0	0.2	0.3	0.25	0.95	1	1	1	1	1	0.99	1	1	0	0	0	0.1
Ghana	1	1	1	0.98	0.45	0.2	0	0.65	0.45	0.98	1	1	1	1	0.97	0.95	1	0.99	0	0	0	0.1
Nigeria	0.6	0.5	0.5	0.5	0.45	0.03	0.15	0	0.05	0.05	0.05	0.02	0.11	0.1	0.09	0.09	0.1	0.09	0	0	0	0.02
Benin	1	1	1	0.98	0.9	0.25	0.45	0.05	0	0.5	0.99	0.99	0.99	1	0.99	0.99	1	1	0	0	0	1
Cameroun	1	1	1	1	1	0.95	0.98	0.05	0.5	0	0.05	0.2	0.2	1	1	1	1	1	0	0	0	0.9
Congo	0.7	0.7	0.7	1	1	1	1	0.05	0.99	0.05	0	0.9	0.9	1	1	1	1	1	1	1	0.95	0.7
Gabon	0.4	0.4	0.4	0.7	1	1	1	0.02	0.99	0.2	0.9	0	0.5	1	1	1	1	1	1	1	0.97	0.95
EG	0.3	0.3	0.3	1	1	1	1	0.11	0.99	0.2	0.9	0.5	0	1	1	1	1	1	1	1	1	0.1
liberia	1	1	1	0.5	0.5	1	1	0.1	1	1	1	1	1	0	0.2	0.1	0.5	0.5	0	0	0	0.1
Sierra Leone	0.8	1	1	0.5	0.5	1	0.97	0.09	0.99	1	1	1	1	0.2	0	0.1	0.8	0.5	0	0	0	0.1
Guinea-Conakry	0.6	1	0.6	0.5	0.65	0.99	0.95	0.09	0.99	1	1	1	1	0.1	0.1	0	0.1	0.1	0	0	0	0.1
Gambia	0.6	1	1	0.55	0.99	1	1	0.09	1	1	1	1	1	0.5	0.8	0.1	0	0.05	0	0	0	0.1
Guinéa- Bissau	0.6	0.7	0.55	0.45	0.95	1	0.99	0.1	1	1	1	1	1	0.5	0.5	0.1	0.05	0	0	0	0	0.1
Mali	0.3	0.7	0.6	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0.1
Burkina Fasso	0.3	1	0.9	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0.1
Niger	1	0.7	0.7	0	0	0	0	0	0	0	0.95	0.97	1	0	0	0	0	0	0	0	0	0.1
Angola	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.09	0.07	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0

Appendix 5.1:
WCA container Traffic (Based on MLTC-CATRAM, 2013)

Traffic (TEU)	Country	2006	2010	2011	2015	2016	2017	2018	2019	2020
Luanda	Angola	377 200	583 300	631 247	865 822	936 992	1 014 012	1 097 363	1 187 566	1 285 183
Cotonou	Benin	140 500	305 000	337 758	507 958	562 514	622 930	689 835	763 925	845 973
Douala	Cameroon	200 300	290 000	340 000	519 577	577 687	642 297	714 132	794 001	882 803
Pointe Noire	Congo Brazzaville	122 600	355 000	442 800	648 334	713 176	784 503	862 964	949 271	1 044 211
Takoradi	Ghana	51 000	53 000	57 000	74 292	79 379	84 815	90 624	96 830	103 461
Tema	Ghana	420 300	590 100	*756 889*	821 786	878 063	938 193	1 002 441	1 071 089	1 144 438
Conakry	Guinée	85 300	120 000	135 075	216 845	244 086	274 749	309 264	348 116	391 847
Abidjan	Ivory Coast	507 100	530 000	546 419	793 119	860 969	934 623	1 014 578	1 101 373	1 195 593
San Pedro	Ivory Coast	49 800	77 000	80 000	111 093	120 597	130 913	142 113	154 270	167 467
Monrovia	Liberia	36 500	53 400	59 746	93 620	104 746	117 193	131 120	146 701	164 134
Nouakchott	Mauritania	43 100	65 700	72 699	108 985	120 595	133 441	147 655	163 384	180 788
Lagos (Apapa+Tin Can)	Nigeria	587 600	1 120 000	1 413 276	1 883 206	2 023 325	2 173 869	2 335 614	2 509 393	2 696 103
Onne	Nigeria	65 000	90 800	97 556	129 994	139 666	150 058	161 223	173 219	186 107
Dakar	Senegal	375 900	349 200	415 592	504 648	529 748	556 096	583 754	612 788	643 267
Freetown	Sierra Leone	35 600	50 000	75 000	106 381	116 095	126 696	138 266	150 892	164 671
Lome	Togo	215 900	339 900	350 000	522 631	577 732	638 643	705 976	780 408	862 687