DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF MARITIME BUSINESS ADMINISTRATION
LOGISTICS MANAGEMENT PROGRAM
MASTER'S THESIS

ASSESSMENT OF CONTAINER TERMINALS PERFORMANCE OF COTONOU PORT AUTHORITY

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THESIS APPROVAL PAGE

DECLARATION

I hereby declare that this master's thesis titled as " **Assessment of Container Terminals Performance of Cotonou Port Authority**" has been written by myself in accordance with academic rules and ethical conduct. I also declare that all materials benefited in this thesis consist of the mentioned resources in the reference list. I verify all these with my honour.

…./…./2023

Tatchégnon Mathieu AKPADE

ABSTRACT

Master's Thesis

Assessment of Container Terminals Performance of Cotonou Port Authority

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Logistics Management Program

The objective of this study was to determine the performance of container terminals handled at Cotonou Port Authority, i.e. Beninese Port Handling Company (SOBEMAP), APM terminal, and Benin terminal (BT). We calculated the technical and scale efficiencies by applying the data envelopment analysis (DEA) method. The number of containers handled in TEU on the terminals was used as the output. The inputs are the quay gantry cranes, the yard cranes, the quay linear, and the container storage space. Data covering years 2016-2020 were collected from the statistical archives of the port of Benin. The results of our analysis showed that the three container terminals are efficient (scores equal to 1) at the technical and scale level except for the year 2016, where the results of the Benin terminal (BT) did not show a good performance which was due to the change of government policy. We discussed the implication of these results and provided necessary recommendations.

Keywords: Cotonou Port Authority, Container Terminals, Performance, Data Envelopment Analysis (DEA).

ÖZET

Yüksek Lisans Tezi

Cotonou Otonom Limanındaki Konteyner Terminallerinin Performansının Değerlendirilmesi

Tatchégnon Mathieu AKPADE

Dokuz Eylül Üniversitesi

Sosyal Bilimler Enstitüsü

Denizcilik İşletmeleri Yönetimi Anabilim Dalı

Lojistik Yönetimi Programı

Bu çalışmanın amacı, Cotonou Benin Otonom limanında elleçlenen konteyner terminallerinin, yani Benin Liman Taşıma Şirketi (SOBEMAP), APM terminal ve Benin terminalinin (BT) performasını değerlendirmektir. Veri Zarflama Analizi (VZA) yöntemini uygulayarak teknik ve ölçek verimliliklerini hesaplanmıştır. Çıktı olarak terminallerde TEU'da elleçlenen konteyner sayısı kullanılmıştır. Girdiler, rıhtım portal vinçleri, tersane vinçleri, rıhtım lineer ve konteyner depolama alanıdır. 2016-2020 yıllarını kapsayan veriler Benin Limanı istatistik arşivlerinden toplanmıştır. Analizimizin sonuçları, üç konteyner terminalinin teknik ve ölçek düzeyinde verimli (1'e eşit puanlar) olduğunu göstermiştir. Ancak, 2016 yılı için, Benin terminalinin (BT) sonuçlarının hükümet politikası değişikliği nedeniyle iyi bir performans göstermektedir. Bu sonuçların etkileri tartışmış ve gerekli öneriler sunulmuştur.

Anahtar Kelimeler: Cotonou Otonom Limanı, Konteyner Terminalleri Performans, Veri Zarflama Analizi (VZA).

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RESULTS, DISCUSSION, AND RECOMMENDATIONS AND LIMITATIONS OF THE RESEARCH

LIST OF ABBREVIATIONS

AFRICAMAX	Africa Maximum vessel
AGV	Automated Guided Vehicles
APM	AP (Anorld Peter)-Moller
BCC	Banker-Charnes-Cooper
BT	Benin Terminal
CCR	Charnes-Cooper-Rhodes
COMAN S.A.	Cotonou Handling Company S.A. (Cotonou Manutention S.A.).
Covid-19	Coronavirus Disease-2019
CRS	Constant Return Scale
CT	Container Terminal
DEA	Data Envelopment Analysis
DEAP	Data Envelopment Analysis Program
DED	Population Studies Branch (Direction des Études démographiques).
DMU	Decision Making Unit
FAH	Free Disposal Hull
GPD	Gross Domestic Product
Ha	Hectare
IP	Performance Indicators
IPA	International Port of Antwerp
ISO/TC	International Standards Organisations-Technical Committee
IT	Information Technology
LOA	Length Overall
LPG	Liquified Petroleum Gas
M	Meters
m^2	Meters Square
MIT	Ministry of Infrastructure and Transport
MMBF	Mean Movements Between Failure
MT	Metric Ton
MTTR	Mean Time To Repair

OSC	Ocean Shipping Consultants
PAC	Cotonou Port Authority
PTE	Pure Technical Efficiency
RMG	Rail-Mounted Gantry
RO-RO	Roll-on Roll-off
RTG	Rubber-Tired Gantry
SC	Stradde Carrier
SE	Scale Efficiency
SFA	Stochastic Frontier Analysis
SOBEMAP	Benin Port Handling Company (Société Béninoise de la Manutention Portuaire).
SONACOP	National Company for the Marketig of Petroleum Products (Société Nationale de Commercialisation des Produits Pétroliers).
TE	Technical Effiency
TEU	Twenty feet equipment unit
UNCTAD	United Nations Conference on Trade and Development
USA	United State of America
VRS	Variable Return Scale
WAFMAX	West Africa Maximum vessel
ZPMC Brand	Zhenuha Port Machinery Company Brand

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INTRODUCTION

The maritime area or seaport is defined as a geographical system that aims to connect continental spaces (Frémont, 1998: 31). It is also a set of land spaces, maritime waters, and installations that, located on the seashores, bring together physical, natural, and organizational conditions that allow the execution of port operations (PAC, 2020: 15). In this maritime area, several actors or shipping companies are involved in the activities of port logistics chain and in the whole chain from the berthing of ships to the exit of goods. The main shackle in this chain is the handling of goods, i.e., the unloading or loading from ship to shore (vice-versa) in a port area where the cargo must be transited in a place, commonly called a terminal. Based on packaging and goods, several types of terminals are observed.

Indeed, the advent of specialized ships, i.e., container ships, has led to the installation of container terminals within ports. Terminals or container yards are equipped with specific lifting equipment and devices to facilitate handling. In addition, goods are packaged in metal boxes (containers) and are only intended for one type of terminal, hence the name "container terminal". Goods packaged in containers that pass through a terminal for the final destination (often landlocked countries), also facilitate loading and unloading operations during the second phase of transport (multimodal transport). Thus, container terminals can be defined as facilities for transferring containers between different modes of transport and provide a package of activities and services to handle and control container flows from vessel to railroad or road, and vice versa (Esmer, 2008: 243).

However, the increase of container ships in the world and the loyalty of liners were facilitated by the growing flow of containers where container terminals are constantly increasing their production capacities in TEUs. For example, in Sub-Saharan Africa, over 10 years (1995-2005), specifically in East, South, and West Africa, container traffic rates increased by +5.8%, +2.5%, and +13.8% respectively (OSC, 2008: 3). Therefore, each handling shipping company had to improve its performance to better meet customer expectations. Performance is often related to efficiency and considered as an exploit; a success obtained by following a process. In other words, the explanation of the term performance is considered as a service whose evaluation can lead to good or bad performance (Azzelarab, 2018: 3-4). Thus, the good performance of a company (terminal) depends on the strategic, tactical, and operational decisions taken by the port operators (Baita and Kpoghomou, 2021: 4).

Due to its geographical position, the Cotonou Port Authority (PAC) has enormous potential to be efficient. Located in the middle of its major competitors in the West African sub-region (Nigeria, Togo, Ivory Coast, etc.) and serving the hinterland countries (Niger, Burkina-Faso, Mali, Chad, etc.), the PAC has the advantage of being strategically and technically performant. In general, the performance of the port requires the full involvement of stakeholders and companies operating at the port. Terminals participate on a large scale in determining the performance of ports. Because all port operations rely on terminals. It's a crucial place for loading and unloading freight. In addition, compared to other countries, little research has been carried out on the evaluation of performance of container terminals in the Republic of Benin. In this study, we aim to assess the performance of container terminals of Cotonou Port Authority (Port of Benin).

To tackle this topic, some questions were developed:

- How to evaluate the performance of the container terminal of a port?
- What are the measurement indicators (output and input) to be taken into account?
- What are the technical efficiencies of container terminals over time?
- What are the scale efficiencies of container terminals over time?

Furthermore, to answer these questions mentioned above, a quantitative Data Envelopment Analysis (DEA) method that determines the efficiency of the container terminals of the port of Cotonou, was used.

The main objective of this study was to determine the efficiency (performance) of container terminals of Cotonou port authority. The specific objectives consisted to:

- Determine the technical efficiency of the container terminals;
- Determine the scale efficiency of the container terminals;
- Determine the nature of the return to scale in order to know the readjustments of terminals or port infrastructures and superstructures.

The current study aims to allow port authorities and seaport container users to have a general idea on the efficiency of the shipping companies operating in the container terminals of Cotonou Port Authority. The outcome of this study would also help the port authorities to know the handling shipping companies that technically and strategically manage well their terminal and used its resources to the optimal size.

The organization of this dissertation is as follows:

The introduction tackled a general context of the topic, provided the definition of the subject, the questionnaires related to the problem, the study objectives, and the importance of the topic;

The first chapter, consisted of tackling the concepts of containerization, terminals, handling equipment, operations of container terminals, and the notion of container terminal performance measurement.

The second chapter, was about the assessment of container terminals performance literatures, presentation of the context and scope of the study (Cotonou Port Authority), and Benin and West Africa Regions port performances.

The third chapter, presented the research methodology, which consisted of tackling the Data Envelopment Analysis (DEA) methods, sampling data (output and input), data collection, model orientation, and the mathematical formulation.

The fourth chapter, was devoted to the descriptive analysis, presentation of the results and interpretations, discussion, and recommendations and the research limitations.

Finally, a conclusion of the paper was made.

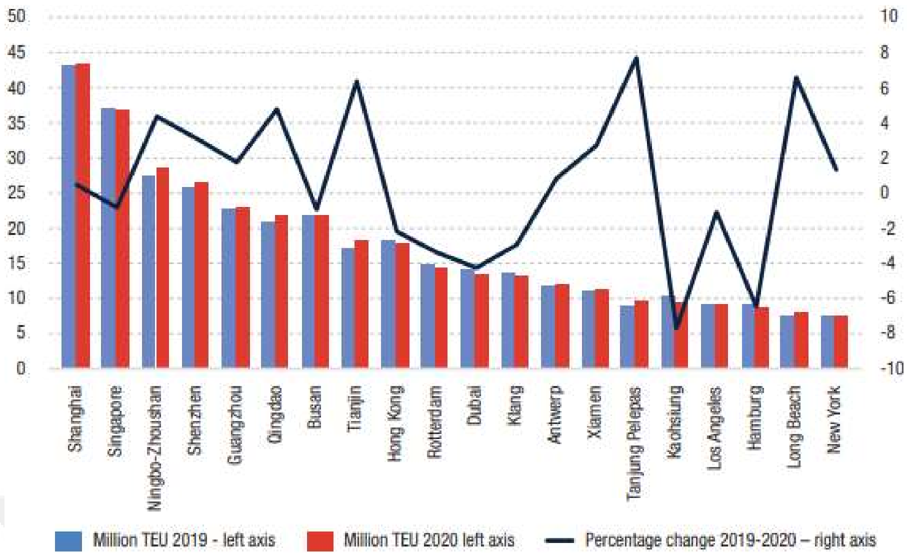
CHAPTER ONE
CONTAINERIZATION

1.1. THE EVOLUTION OF CONTAINERIZATION

The idea of Malcolm McLean has improved containerization which has become the backbone of international trade. In 1956, American entrepreneur Malcolm McLean, a novice in the field, successfully achieved a load of 58 aluminum truck trailers into ships to reach the city of Houston (USA). Following this success, the idea of dissociating the chassis and the trailer from the body started. The body, commonly called "Container" has become the most used freight transport packaging in international trade. A year later (1957), with the agreement of the ISO/TC 104 technical committee (Baita & Kpoghomou, 2021: 4), Malcolm McLean created the concept of multi-modality that can permit the transport of cargoes through other continents without loading/unloading goods from containers. Ten years later (1966), for the first time, the Sea-Land company of Malcolm McLean transported containers from New York to Rotterdam. Since then, the concept of containerization has been adopted worldwide.

Today, all over the world, major ports are investing tremendous funds to modernize or install container terminal infrastructure. For instance, Antwerp invested a sum of four (4) billion dollars and ranked among the best ports in the world between 1987-1997 (Robin, 2011). However, nowadays, the ports of Hong Kong, Singapore, and mainland China remain the best in the world. Figure 1 illustrates the top twenty (20) container ports and the change in their rate between 2019 and 2020.

Figure 1: Leading 20 Global Container Ports, 2019-2020 (TEU, Percentage Annual Change)



Source: UNCTAD, 2021.

To date, the number throughput of containers transported around the world continues to increase. Although the COVID-19 pandemic has had an impact on the maritime transport sector, a great change has not yet been observed in the number of containers operated in this period. In 2019, container throughput was 825.3 (million TEU), and in 2020, it decreased by (-1.2%) (i.e., 823.6 million TEU). Despite this, the volume of TEUs in the African continent sticks remains unchanged (UNCTAD, 2021: 17) while some changes have been observed in other continents.

Table 1: World Container Port Throughput by Region (Million TEU and Annual Percentage Change)

	2019	2020	2019–2020
Asia	534.8	532.7	-0.4%
Africa	32.5	32.5	0.0%
Latin America and the Caribbean	60.1	59.0	-1.8%
Europe	122.6	117.4	-4.2%
North America	62.4	61.2	-1.9%
Oceania	12.9	12.8	-0.8%
World Total	**825.3**	**815.6**	**-1.2%**

Source: UNCTAD, 2021.

1.2. ADVANTAGES AND CHARACTERISTICS OF THE DIFFERENT TYPES OF CONTAINERS

In intermodal freight transport, several containers are used depending on the variety of goods. The containers are standardized to ISO 668 and ISO 1496. Today, with the evolution of container shapes, different types of containers 20', 40', and 45', easily identifiable, were observed. For instance, TEU containers (the most used) have 33.1 m^3 and external dimensions “6.06m * 2.44m *2.59m. Those of 40’ and 45’ have respectively 67.5 m^3 and 86.1 m^3. The ISO container, a packaging unit for goods in transport, has certain advantages:

- Durable and strong enough to withstand multiple uses;
- Designed to facilitate the transport of goods by one or more modes of transport without breaking loads;
- Equipped with accessories for easy handling;
- Designed to protect goods against bad weather, theft, damage, and loss;
- Ensuring the speed of operations (e.g. the simplification of customs formalities; etc.)

The characteristics of the different types of containers used in intermodal transport are summarized in Table 2.

Table 2: Different Types of Containers

Types of containers	**Definitions or characteristics.**	**Images**
Refrigerated containers	Have a cooling unit installed inside depending on the capacity. Suitable for transporting perishable goods (vegetables, fruits, flowers, meats, etc.).	
Tank containers.	Have tanks inside and can transport liquid substances (e.g. cooking oils, mineral waters, rum wine, etc.)	

Open Side Containers.	Open on the side of the length and allow the loading of bulky goods.	
Isothermal containers.	Presence of insulated walls, which contain heating and cooling installations. Suitable for the transport of perishable foodstuffs under controlled temperatures.	
Flat rack containers (Also called platform containers with open sides).	Intended for loading heavy and bulky packages. Presence of fixed or removable end walls and suitable for the transport of goods such as steel bars, steel sheets and coils, pipes, heavy machinery, etc.	
Open top containers.	Suitable for all forms of goods. Roofs are made of tarpaulins and facilitate the rapid loading and unloading of bulky goods.	
Standard or dry containers.	Suitable to transport dry materials (e.g. furniture, bags, sheet metal bundles, crates, etc.)	
Ventilated containers	Correspond to the standard containers. Composed of two side panels and a roof panel and allow products to be cooled.	
Wide pallet containers.	Have the shape of the 45' containers, the length of which differs from the other types and corresponds to the standard of the pallets.	

Source: Author based on www.1001containers.fr;

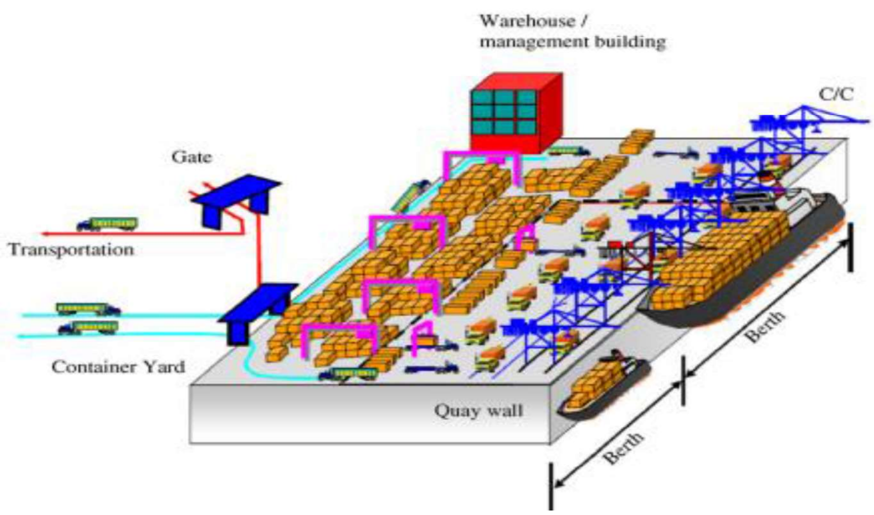
1.3. CONTAINER TERMINAL

Seaport container terminals are areas in the port where containers are transshipped from deep-sea vessels to feeders, trucks, trains, and barges and vice versa (Kemme, 2013: 2). According to the Wikipedia encyclopedia, a container terminal is defined according to the means of transport used. The container terminal is therefore described as a container terminal when the transshipment of containers is often carried out between a container ship and a land vehicle, truck, or train. It is categorized as an inland container terminal when transshipment is between two land vehicles. For example, trains and trucks. However, a container terminal is also described in terms of its equipment and stacking system (Steeken et al., 2004: 8).

A container terminal (CT) combines several elements. According to Na and Shinozuka (2009: 723), a CT is composed of a gate, container storage space, berth, warehouse, container freight station, and handling equipment freight. Moreover, Benghalia (2015: 26-27) reports that a CT is equipped with a quay, storage areas, quay cranes, riders, trucks, or automatic guide vehicles.

Steeken et al. (2008: 8-10) slit the elements that make up a CT into two subgroups: the stock and the transport vehicles. The “stock” includes yard piles, ships, trains, and trucks while the “transport vehicles” category takes into account cranes and vehicles for horizontal transport.

Figure 2: Container Terminal



Source: Na and Shinozuka, 2009: 724.

1.3.1. Definitions and Terminologies

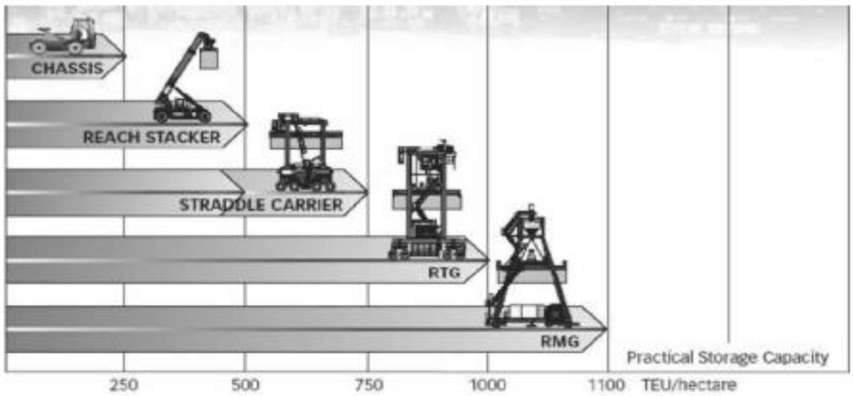
- Crane is a lifting and handling device reserved for heavy loads. This hoist is constructed differently depending on its use (Anonymous, 2014). There are quay cranes and mobile cranes:
  - Quay crane is a device used to load and unload ships.
  - Mobile crane (on wheels or tracks) is a truck with a crane allowing the handling of loads.
- Stackers are Device derived from pallet trucks, equipped with a lifting assembly to lift the load (Anonymous, 2014).
- Overhead crane is a handling device for lifting and transferring heavy loads. It consists of one or two steel beams, motorized by 1, 2, or 4 motor(s) or non-motorized, on which a hoist or winch, motorized or not, is placed. It can be suspended or placed on 2 rails (Anonymous, 2014).
- Gantry crane is a crane built atop a gantry, which is a structure used to straddle an object or workspace. It can range from enormous ''full'' gantry cranes, capable of lifting some of the heaviest loads in the world, to small shop cranes, used for tasks such as lifting automobile engines out of vehicles (https://en.wikipedia.org/wiki/Gantrycrane).
- Quay is a levee usually lined with stones, arranging the basins of a port or the shore of a river, a canal, or a lake, intended to retain the shore or to facilitate the docking of ships for their unloading (PAC, 2017).
- Berth is basically an area where the ship is moored onto the bollards and where the cargo is loaded or discharged on and off the ships (Manadiaar, 2021).
- Container yard is an area where containers are stored in a terminal or a dry port while waiting to be loaded or unloaded on a ship or other means of transport.

1.3.2. Capacity of Container Terminal Handling Equipment

Operations on a terminal are complex and require a lot of resources. To lighten the task and smooth a rapid operation, handling companies are committed to making the latest quality equipment available to handlers. Kim and Günther (2007: 6-7) defined the capacity of yard cranes according to the performance of the number of TEU containers per hectare. Thus, chassis-based transporters, reach stackers, straddle carriers, rubber-tired gantry (RTG) cranes, and rail-mounted gantry (RMG) cranes can store respectively 250, 500, 750, 1000, and 1100 TEU container capacity per hectare. Gantry cranes like RMG and RTG are specialized in stacking operations. They can stack up 4 to 10 high and perform twenty (20) container turnouts per hour (Steeken et al., 2004: 8-10). Moreover, handling equipment like reach stacker and straddle carrier (SC) are capable to pick up containers. They have the ability to stack containers up to 3 or 4. As for AGVs (Automated Guided Vehicles) and serve 40'/45' container loading operations, or at the same time two 20ft containers with gantry cranes.

Figure 3: Handling Equipment

a. Classification of Handling Equipment (TEU/hectare).



Source: (Kim and Ghunter, 2007: 6).

b- Quay crane (dual-trolley cranes).

C- AGVs (in front of quay cranes).

Source: Steeken et al. (2004: 10).

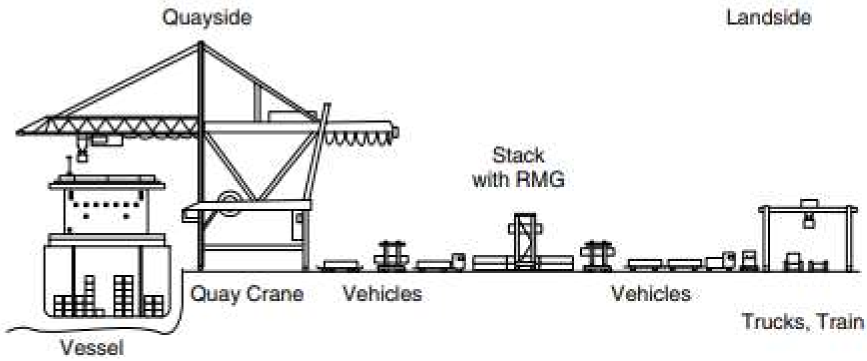
Finally, the capacity of quay cranes is estimated in metal boxes (containers) per hour. The estimate of the technical efficiency of the containers handled varies between 50 and 60 boxes per hour; and the one for operational capacity is between 20 and 30 boxes (Steeken et al., 2004: 8).

1.4. OPERATIONS OF CONTAINER TERMINALS

The operations of a CT depend on the management and organization policy of the company. According to Henesey (2006: 26; 54), operations in a container terminal are organized into four subsystems. The performance of one subsystem is related to other. Therefore, interconnection between subsystems determines the total performance of the container terminal. The operations on the terminal can be summarized as follows:

- Ship/shore operation area concerns loading and unloading containers from the ship take place. The major issue at this stage is the allocation of berths and quay cranes.
- Transfer zone concerns the transfer of containers from one place to another, i.e. from the quay to the storage zone, or from this storage area to loading in another mode with handling equipment.
- The Storage area is an operation where the containers are stacked, handled, or sorted. It is made up of some lanes called bays allowing the stacking of containers.
- The delivery and reception consist of moving the containers from the storage zone to the exit door for other modes of transport i.e. the transport of containers to the countries of the hinterland (case of import).

Figure 4: Container Terminal System



Source: Steeken et al. (2004:13).

Vis and de Koster (2003), described the operating process of a container terminal in five main phases: the arrival of the ship, unloading/loading of the ship, internal transport of the containers from the ship to the storage place, container stacking, inter-terminal transport and other modes of transport (land, rail). In import and export, operations are same but inversely operated. After the ship arrives at the quay, operations at the terminal begin. Operations are delimited into two zones. The first includes ship loading/unloading activities and the transfer of containers to the storage location. The second zone takes into account storage or stacking operations, and then the transfer of containers from the storage location of the terminal to other modes of transport. For instance, based on Casablanca port terminal realities, the scholar delimits the operations of the container terminal into three zones:

- Reception/delivery area consists of receiving containers from other modes of transport while waiting for them to be loaded onto the ship.
- The courtyard or park zone is a zone that takes into account the activities of sorting, processing, and rearranging containers.
- The quayside is where the ship loading and unloading operations take place.

Dubreuil (2008: 8-9), categorizes the operation areas on a container terminal into three parts, namely the port operation area, the terminal storage area, and the land operation area. In the first zone, the loading and unloading operations of ships and barges take place. In the second zone, storage and handling activities take place in the yard. The land operation zone concerns the transfer of containers to land modes (truck, train, etc.).

1.4.1. Optimization of Operations in a CT

Optimization consists of making a system, design, or decision as efficient or functional as possible (Pernia and Scattergood, 2013). In the terminal system, it's not just about boosting productivity and reducing cost; but also opting for good management. The latter must take into account the service time of the vessel, the capacity of the terminal, and the cost of operation per movement. In the current study, we aimed to make container handling operations in the terminal more efficient.

However, to optimize the container handling operations on a terminal, the RTG gantry time must be minimized; the route of the towing vehicles on the container terminal and the rate of the gantry at the quay must also be maximized (Bouh, 2012: 63). Thus, planning of these optimization factors is necessary.

1.4.1.1. RTG Gantry Operations Planning

Planning at the RTG gantry level consists of optimal use of the container yard by promoting faster loading or storage operation rates. In addition, to optimize the movements of RTG in the container yard, some measures must be taken (Bouh, 2012: 64):

- ❖ Insert all data in real-time into the RTG management system allowing better use of terminal resources;
- ❖ Avoid loss of time for vehicles transporting containers;
- ❖ Have precise and real-time information on the arrival of vehicles and the location of storage.

1.4.1.2. Tractor/Truck Planning

Tractors and trucks play a fundamental function in moving containers. They permit the movement of the containers from the RTG to the quay gantry (export). Better planning of the road would ensure the quay gantry's reasonable load rate.

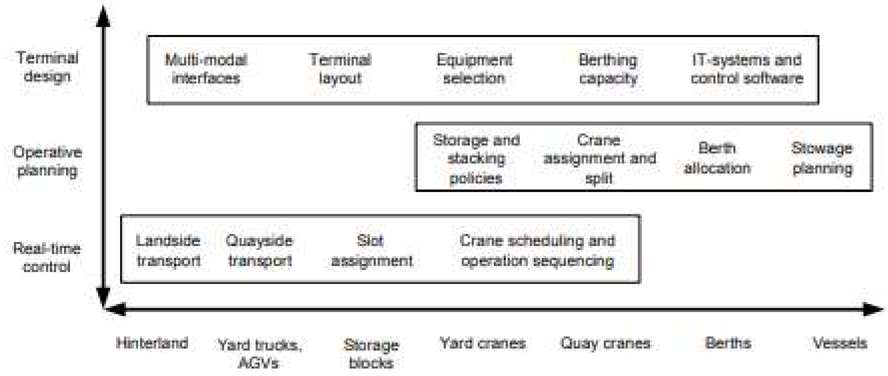
1.4.1.3. Gantry Cranes Planning at the Quay

Planning gantry cranes at the quay consists of optimizing the rate of loading or unloading containers on a ship. That's the main component of any logistics activity in a terminal. The higher the rate of loading (unloading), the faster the container ships sailed from the wharf.

1.4.2. Problems of Planning and Controlling Operation in a Container Terminals

The organization of operations in a terminal causes several decision-making problems. The decision problems faced by terminal managers are planning and logistics control (Kim and Günther, 2007; Henesey, 2006; Vis and de Koster, 2003). According to the diagram of Kim and Günther (2007: 7-9), three major decision problems were identified:

Figure 5: Logistics Planning and Control Issues in Seaport Container Terminals



Source: Kim and Günther, 2007: 7.

The configuration of the terminal which concerns the facility of access to the terminal by other modes of transport (land or rail), the arrangement and configuration of the storage spaces, the selection of sophisticated or automated equipment, the capacity of the quay for handling operations, and the configuration of IT tools to identify containers in a span short time.

Operative planning links to the logistics planning of all operations on the terminal. It takes into account the allocation of quays while focusing on the time that the ship must spend in port; the preparation of the cranes which will be available throughout the operations; stowage planning or sequencing, i.e. the arrangement that the containers must take in the ship, based on their destination, their weight and the type of container; container storage stacking policy; and finally the organization of workers for the execution of the tasks entrusted to them.

Just-in-time operation management or control: remains the most important. It concerns the planning and organization within a time frame of activities at the terminal, including the definition of the short route of road transport and from the quay to the place of storage.

Vis and de Koster (2003) also identify planning and control problems at three levels: at the strategic level, the decision problems generally encountered are the layout of the containers on the terminal, the handling equipment allocated and the modes of operation on the terminal. Decisions at this level should cover a period ranging from one to several years; at the tactical level, the information relating to the storage of the containers must be defined. This information should be used to plan operations over a period ranging from days to months; at the operational level, the daily tasks and problems of any organization on CT must be solved by the operations manager.

1.5. CONTAINER TERMINALS PERFORMANCE MEASUREMENTS

1.5.1. The Notion of Performance

In business, the concept of performance is often used and assimilated into the notions of effectiveness and efficiency (Bocco, 2010: 118). Pesqueux (2004) defines the concept of performance according to the domains (Artistic, physical, organizational, managerial, sporting, narrative), for which it takes one meaning. From an organizational point of view, performance is perceived as an “object” or as a “process”. It is an accomplishment of an act or a process that leads to a quantified result from a ranking perspective. It is also a value judgment in a given time frame. On the managerial side, performance is defined according to the objectives set over a given period. Bourguignon (1997:90) clarifies the notion of performance in the management domain according to three dimensions:

- The first relates to "action" i.e. the accomplishment of a task and not a result dependent on a reference frame.
- The second is related to the "result" i.e. the ex-post evaluation of the result.

- For the last one, which is related to "success" the performance depends on the objective set by companies and the social conditions for assessing success according to a measurement scale (Pesqueux, 2004).

According to Azzelarab (2018), performance is defined as an achievement, a remarkable result obtained during a process. The explanation of the term performance refers to a service whose evaluation may lead to a positive result or not. In addition, the author associates the term performance with efficiency and productivity. For example, firm performance measurement is done to the ratio of productivity (output/input)*.

1.5.2. Efficiency and Productivity

Efficiency is minimizing unnecessary effort and expense to achieve maximum output. Production is the efficiency of productive efforts. In other words, the productivity (output) of a company depends on the efforts or resources (inputs) implemented to achieve maximum production. The total factor of manufacturing company production is the ratio of outputs and inputs (Wang et al., 2005). In our study, we can consider port container productivity as a partial factor of production.

According to Gonzalez and Trujillo (2009: 160), the two terms (productivity and efficiency) are occasionally used to compare the performance of companies. The measurement of efficiency is nearly linked to productivity; i.e. the two concepts are analogous. For example, when there is a change in efficiency, the firm productivity also changes. However, factuality, the two terms are distinctive. Figure 6 clarifies the two concepts. Based on the figure, we define the curve (OF') as the production frontier, (y) output, and (x) the input. The production frontier is the maximum number of outputs (containers) that could reach each level of inputs (e.g: RTG, cranes, storage space, etc). In terms of performance, the production units situated below or above the production frontier (OF') are technically inefficient and efficient respectively. The figure shows that points C and B (decision-making units-DMU) are efficient because they are on the production frontier. Point A below (OF') means it's not efficient.

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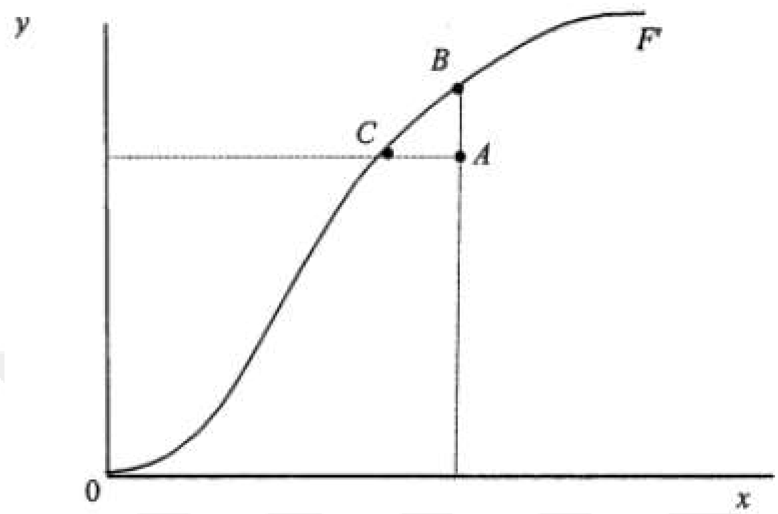
* Input: all the factors involved in a production (raw material, energy, labor). Dictionary definition-Larousse.
* Output: the result of production. Dictionary definition-Larousse.

Although the DMUs (A and B) have the same inputs, they do not produce the same outputs.

Figure 6: Production Frontiers and Technical Efficiency



Source: Coelli et al., 2005:4.

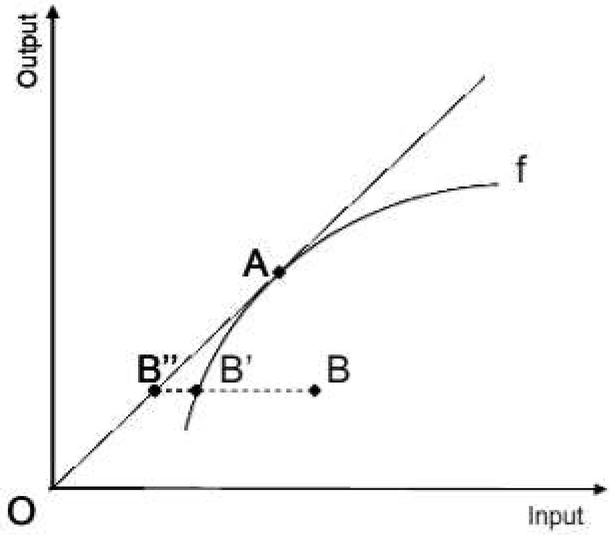
1.5.2.1. Technical and Scale Efficiency

Technical efficiency is defined as relative productivity at a certain time, space, or both. The scale efficiency refers to a discrepancy between the size of the current production and with optimal production. In economics, with output-oriented, technical efficiency corresponds to the production frontier. Input-oriented corresponds to the cost frontier (Monteiro, 2015). The figure below describes how pure technical efficiency and scale efficiency work. Curve f represents the frontier of pure technical efficiency. A is the optimum point of scale operation. By orienting the model towards the input (input-oriented), the efficiency score of point B is less than 1 with respect to the curve f (Pure technical frontier) and the line of point A (Scale efficiency). The formulas for point B inefficiency are as follows:

Pure technical efficiency = OB'/OB< 1

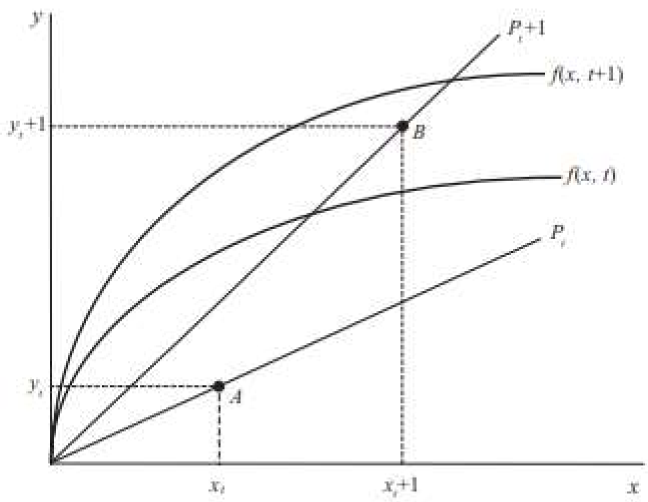
Scale efficiency = OB'/OB" < 1

Figure 7: Scale and Pure Technical Efficiency



Source: Monteiro, P.C., 2007: 37.

Figure 8: Change in Efficiency, Scale and Technical Change



Source: Gonzalez and Trujillo, 2009: 161.

Figure 8 illustrates the case of Scale and Technical change in the port sector. By focusing on the figure, we observe that the two production frontiers "f (x, t)" and "f (x, t+1)" have been represented at two different periods (t_1; t_2). Thus, during these two periods, the company acquired firstly goods handling equipment and then trained its users. At time t, company A with productivity (P_t) and a production input x_t doesn't show a sign of efficiency i.e., point A ends up completely below the frontier f (x, t). At time t+1, i.e. after the training given to the users of this handling equipment, we observe a change in technical efficiency at the level of company B. Consequently, point B is closer to the frontier f (x, t+1) (Gonzalez and Trujillo, 2009: 161).

1.5.3. Performance Measurement Indicators for Seaport Container Terminal

Measuring performance is extremely importance for any enterprise. Particularly in the port sector, determining performance is essential to the national economy of a country, the development of industries, and the well-being of the population (Esmer, 2008: 240). According to UNCTAD (1976: 2), considerable reasons are the basis of the determination of performance indicators (IPs):

- ❖ Comparison of the performance against the targeted objective;
- ❖ Appreciation of the competition in terms of performance;
- ❖ Application of IPs as inputs that serve as negotiating parameters for port congestion surcharge, port development, port tariff considerations, and investment decisions.

The performance measurement indicators are multiple and vary according to the aim of the research. In UNCTAD (1976), IPs are classified into two groups: financial and operational indicators. The operational indicator would be ideal for the context of our paper. Thus, the operational indicators are detailed in the table below:

Table 3: Operational Indicators

Indicator	**Units**
Arrival late	Ships/days
Waiting time	Hours/ships
Service time	Hours/ships
Turn-round time	Hours/ships
Tonnage per ship	Tons/ship
Fraction of time berthed ships worked	-
Number of gangs employed per ship per shift	Gangs
Tons per ship-hour in port	Tons/hour
Tons per ship-hour at berth	Tons/hour
Tons per gangs-hour	Tons/gangs-hour
Fraction of gangs-time idle	-

Source: UNCTAD (1976:9).

However, Ibrahimi (2009: 7-10) stated port performance indicators are not only limited to financial and operational aspects but they also take into account environmental, security, safety, and exchange facilities. For operational indicators, the author classifies the performance indicators into seven categories: General measurement units (Net productivity, Idle times or interruptions and Working intensity or gang use), berth throughput or trade, ship and cargo times, berth occupancy, ship productivity, labor productivity, and equipment productivity.

Jo and Kim (2019) developed nineteen (19) key performance indicators used to assess the performance of cranes in container terminal operations. Among these IPs, two are the most marked: Mean movements between failure (MMBF) and Mean time to repair (MTTR). MMBF consists of determining the frequency of failures and minimizing and preventive the maintenance in order to increase the reliability of equipment. MTTR determines the need for spare parts. It expressed in the average time spent on maintenance per unit failure.

CHAPTER TWO
ASSESSMENT OF CONTAINER TERMINALS PERFORMANCE

2.1. ASSESSMENT OF CONTAINER TERMINALS PERFORMANCE: LITERATURE REVIEW

In recent years, a lot of scientific research on performance evaluation has flooded the world of maritime transport especially on ports and container terminals. The analysis methods commonly used are the DEA (Data Envelopment Analysis) and the stochastic frontier method (SFA). The SFA method is a parametric approach that follows a distribution law. To estimate a production function, the SFA uses econometric tools. Inversely, DEA use non-parametric approach that does not follow a distribution law. For the construction of its production frontier, the DEA relies on linear programming (Lakhloufi and Sekali, 2022). Some studies using DEA and SFA methods in the maritime industry are summarized below:

Van Dyck (2015) used DEA approach to assess the efficiency of West African ports such as port of Tema in Ghana, port of Lomé in Togo, Port of Abidjan on the Ivory Coast, port of Dakar in Senegal, port of Cotonou in Benin, and Lagos port complex in Nigeria. The investigation of the study was made according to the orientation of the inputs including the total length of the quay, the capacity of the terminal in hectares, the number of reach stacker machines, the number of gantries at the quay, and the number of yard gantries and quays. The only output used is container throughput. The results of this study showed that the port of Tema was the most efficient and the less one is the port of Benin.

Lakhloufi and Sekali (2022) examined port performance of four different African countries Morocco (port of Tangier Med), Kenya (Mombasa), Ivory Coast (Abidjan), and South Africa (Durban) using DEA methods with a focus on output (port traffic). The inputs used in this work are the number of docks, the length of docks, and the number of cranes. Result from analysis of the DEA-CRS and DEA-VRS model, it appeared that the port of Durban occupies the first place in terms of efficiency, and the other ports like Tanger Med, Abidjan, and Mombasa complete the podium. The port of Durban is the only one with an efficiency score of 1.

Birgun and Akten (2005) applied the DEA technique to determine the efficiency of ten (10) container terminals located in the Mediterranean Sea and Marmara area. The performance indicators used to measure the efficiency of the terminals are the length of the quay, the number of handling equipment, the storage capacity as input, and the throughput of containers in TEU as output. Two objectives were considered during analysis. The first goal used DEA-CCR technique (output-oriented) to maximize container throughput while minimizing resources. The results showed that the CT-1 performed better than the others. The second objective used CCR/AR method to examine the efficient use of resources. As a result, the CT-5 terminal manages its resources well than the other terminals.

Cullinane et al. (2006) analyzed the technical efficiency of 57 container ports while comparing the results of DEA and SFA methods. For the DEA, the CCR and BCC models were used. Results showed that BCC model are more efficient than CCR model (22 Vs 9 terminals). For the SFA method, four likelihood ratios (harf-normal, Truncated Normal, Exponential, and Gamma) are calculated. The data from the four models vary by the production function. Overall, the comparison of the results of the efficiency of the two methods (DEA and SFA) showed that the DEA method presents more significant technical efficiency scores.

In Hlali (2018), the two methods (SFA and DEA) commonly used to determine the technical efficiency of ports are applied. The study aimed to maximize container throughput. Data from twenty-six (26) ports, including output (container traffic) and inputs (total quay length, total terminal space, storage capacity, and draft) were used. Results showed that the average efficiency score of DEA was less significant than the one of SFA. In addition, the comparison results proved that the ports of Shanghai, Singapore, Shenzhen, Ningbo, and Dalian were the most ranked.

López-Bermúdez et al., (2019) conducted their research on the efficiency and productivity of container terminals in Brazilian ports. The data used are the panel type, i.e. over several years (2008-2017). To assess the efficiency of the twenty ports, variables such as inputs (call rate of ships at the port, number of gantry cranes and mobile cranes), output (volume of containers), and exogenous factors (RTG, draft, and location ports) were used. SFA methods and port performance index were also applied.

Results of SFA showed that the call rate of ships at the port and the gantry crane are factors favoring the productivity of containers in the twenty Brazilian ports.

Almawsheki and Shah (2015) analysed the technical efficiency of 19 container terminals in the Middle East Region. The DEA-CCR method was used to assess the efficiency. The data used are cross-sectional. Results from analysis of the DEA (Input orientation) showed that 16 (scores under 1) of the terminals are inefficient and 3 terminals (Jebel Ali, Salalah and Beirut) are efficient with scores 1.

Wang et al. (2003) assessed the productivity efficiency of container terminals by comparing the results of two models DEA and FDH (Free Disposal Hull). However, to analyze data from both methods, the DEA-SOLVER-PRO.3 software was used. With input orientation, respectively, the results of DEA-CCR and DEA-BCC (we are only interested in the DEA method) showed that nine (9) and twenty-three (23) of the 57 container ports are efficient.

Tongzon (2001) applied the DEA method to determine the efficiency of sixteen ports: 4 Australian and 12 international container ports. Two outputs freight rates (TEU containers) and the rate of work of the ships; and six inputs number of cranes, number of berths, number of tugs, terminal area, time spent in port by the vessel, and number of employees were used. DEA-CCR and Additive DEA were models used for analysis. The inappropriate and unclear results (e.g. inefficiency of all port) obtained when considering the two outputs have led to the consideration of freight rates (TEU containers) as a single output; and as results, some ports were identified to be efficient while others were not. For instance, the ports of Melbourne, Rotterdam, Yokohama, and Osaka were inefficient.

Kalgora et al., (2019) studied the performance of five ports in the West African region. Ports efficiency was determined based on the DEA model, using three different methods BCC, CCR, and windows I-C. The data analyzed was panel type (2005-2016), involving one output variable (Containers-TEU) and seven input variables (quay length, terminal area, quayside crane, yard gantry cranes, reach stackers, draft, and container throughput limit). Results indicated that the ports of Lagos, Tema, and Lomé are efficient under the assumption of constant and variable returns to scale whereas the ports of Cotonou and Abidjan are technically efficient and inefficient in terms of returns to scale.

Kuo et al., (2020) investigated the competitiveness and performance of Vietnamese ports. The measurement technique used was the DEA method. Context-dependent DEA approach was used to determine the performance of fifty-three ports. The area of the terminal, the length of the quay, and the handling equipment were considered as inputs while the volume of cargoes and the call of ships were considered as outputs. Results revealed that all Vietnam ports are inefficient (PTE < 1).

By using DEA model, Dias and his colleagues determine (Dias, J.C.Q. et al., 2012) the efficiency of ten container terminals in Iberia. The studies were conducted towards output orientation. Their results revealed that among ten terminals, half (Sines, Leixões N, Alicante, Valencia and Algeciras) of them is efficient at a hundred percentage performance levels.

Cullinane, K. et al. (2004) conducted studies of twenty-five world's major container ports. The interest of their studies, was to identify over time the efficiency of production of the different ports. To achieve their goals, they used the DEA-Windows method (BCC and CCR) and panel data. The result of this study showed that the efficiency of container ports could differ over time with different scores. In addition, the study emphasized that scale of production was not related to inefficiency in most ports.

Nguyen, H.-O., et al. (2015) compared the result's consistency of forty-three Vietnamese ports from three different methods: SFA, simple DEA, and bootstrapped DEA. The analyses showed that Bootstrapped DEA presents more appropriate and consistent results than the other two methods. However, the result of SFA compared to those of the two DEA methods are more consistent. In addition, this inefficiency of DEA methods against SFA comes from that of standard-DEA.

Niavis and Tsekeris (2012) examined the causes of container port inefficiencies in the South-East Europe (SES) region. For this investigation, thirty container ports were selected on the basis of an operational capacity of more than twenty thousand containers (TEUs) each per year. Among the thirty ports, the DEA's analysis reveals that the ports of Izmir and Gioia Tauro are completely efficient (CRS=VRS=1). Nevertheless, the average of the 30 SEE-region ports is technically inefficient with a score less than 0.5, i.e. 0.417. The main reason for this inferiority of the score came from the Balkan ports.

Schøyen and Odeck (2013) assessed the performance of Norwegian, Nordic and UK ports. The objective was to determine the performance of the Norwegian port while comparing it to the two other's regions ports. The results of the DEA's analysis revealed that the Norwegian port performs well technically and scale compared to the ports of Nordic and UK. The result also specified that, except the port of Oslo, all other Norwegian ports operate with increasing returns to scale.

Wu and Goh (2010) examined the efficiency of 21 container ports in the emerging (BRIC nations/N-11) and advanced (G7) markets. The results of the analysis of DEA-BCC, DEA-CCR, A&P models show that no port classified in the advanced nations is efficient. Only those in the emerging market are efficient. For instance, Shanghai (China), Chittagong (Bangladesh), and Santos (Brazil) occupied the top rank.

Al-Eraqi et al. (2009) evaluated the efficiency and performance of twenty-two ports in East Africa and Middle East by applying the data envelopment analysis Malmquist productivity index measurement. As result, they noticed that the majority of CTs studies during the period (2000-2005) have increased their total productivity. Furthermore, they stated that half of 22 CTs have their total factor productivity less than Malmquist mean score (1.093).

By applying DEA method, Ablanedo-Rosas and Ruiz-Torres (2009) examined the efficiency of Mexican coastal ports. They benchmark the ports based on different nature of operations. By combining the cargos and cruise operations, the result revealed that among twenty-nine ports, seventy-seven are efficient. For cargo operations only, eight ports are efficient. Finally, for cruise operations, four ports are performants. Through all this analyses, the port of Manzanillo, COL. Proved to be efficient.

Wu and Liang (2009) measured the performance and benchmarking 77 container ports/terminals in the world. The sample includes 28 terminal operators from Asia, 22 terminals from Europe, 12 terminal ports from North America, 7 terminals from Latin America, 4 terminal operators from Africa and 4 terminals operators from Oceania. The DEA-BCC method and cross-sectional (single year 2007) were used. The result revealed that 33.8% of the container terminals are efficient and on the production frontier.

Table 4: Summary of Studies on Container/Port Performance Measurement Using DEA and SFA Methods

Authors	DEA	SFA	Outputs	Inputs	Exogenous factors
Tongzon, (2001).	×		Ships work rate; freight rate (TEU).	Number of cranes, number of berth, number of tugs, terminal area, time spent in port by the vessel, and number of employees	
Wang et al. (2003).	×		Container throughput (TEU).	Quay length (m), terminal area (ha), quayside gantry (number), yard gantry (number), straddle carrier (number).	
Cullinane, K. et al. (2004).	×		Throughput (TEU)	Quay length, terminal area, quayside gantry, yard gantry, straddle carrier.	
Birgun and Akten (2005).	×		Throughput of containers in TEU.	Length of the quay, the number of handling equipment, the storage capacity.	
Cullinane et al. (2006).	×	×	Container throughput (TEU)	Terminal length (m), terminal area (ha), quayside gantry (number), yard gantry (number), straddle carrier (number).	
Al-Eraqi, A.S. et al. (2009).	×		Ships call; Containers throughput (TEU)	Berth length (M); Quay crane; RTGs; Terminal area (M^2)	
Ablanedo-Rosas, J. H. and Ruiz-Torres, A. J. (2009)	×		Number of cruise passengers; Number of cruise ships; Number of cargo ships; Number of container in TEUs; Volume of freight handled (tons).	Lengh of quay line (m); labour units; storage capacity (m^2).	
Wu, J. and Liang, L. (2009)	×		Container throughput (TEUs)	Capacity of cargo handling machines; number of berths; terminal area; storage capacity.	
Wu,Y.-C.J, Goh, M. (2010).	×		Pieces of equipment (number); containers (TEUs)	Terminal area (ha), Total quay length (m).	

Dias, J.C.Q. et al. (2012).	×		Throughput in TEU	Number of quay cranes, terminal area, number of yard equipments, quay length	
Niavis and Tsekeris (2012)	×		Throughput in TEU	Number of berths, length of quay, and cranes.	
Schøyen and Odeck, (2013).	×		Container handling trucks; Container throughput	Berth length, terminal area, yard gantry cranes straddle carriers.	
Almawsheki and Shah (2015).	×		Throughput (TEU)	Terminal area (ha), quay length (m), quay crane (no.), yard equipment (no.), maximum draft (m).	
Nguyen, H.-O., et al. (2015).	×	×	-	-	
Van Dyck (2015).	×		Container throughput (TEU)	The total length of the quay, the capacity of the terminal in hectares, the number of reach stacker machines, the number of gantries at the quay, and the number of yard gantries and quays.	
Hlali, A. (2018).	×	×	Container traffic.	Total quay length, total terminal space, storage capacity, and draft	
López-Bermúdez et al. (2019).		×	Volume of containers	Call rate of ships at the port, number of gantry cranes and mobile cranes.	RTG, draft, and location of ports.
Kalgora et al. (2019).	×		Containers in TEU	Quay length, terminal area, quayside crane, yard gantry cranes, reach stackers, draft, container throughput limit.	
Kuo et al. (2020).	×		Volume of cargoes, call of ships.	The area of the terminal, the length of the quay, and the handling equipment.	
Lakhloufi and Sekali (2022).	×		Port traffic	The number of docks, the length of docks, and the number of cranes	

Source: Author.

2.2. PERFORMANCE AND MARKET TRENDS IN WEST AFRICAN PORTS

In West Africa, all ports seek to increase their traffic volume and to serve landlocked countries such as Niger, Burkina Faso, and Mali in large quantities. This leads West African ports to live in a very competitive atmosphere.

Lihoussou (2014:101-102), examined the data from 2004 to 2010. It results reveal that the port of Lomé is growing by 109% forefront of the ports of Cotonou (75%), Abidjan (27 %), Conakry (21%), Dakar (10%), and Tema (-16%) in terms of total traffic volume. For the "Hubs and Spoke" system, i.e. goods in transit, the port of Cotonou stood out in first place. The following table shows the data and growth of each port between 2004 and 2010. This performance analysis was done without the port of Lagos which is a major port on the West African coast due to the unavailability of data.

Table 5: Port Transit Traffic From 2004 to 2010 (1000 tons)

	2004	2005	2006	2007	2008	2009	2010	Growth in %
Abidjan	530	762	1002	1278	1016	1258	1038	96%
Tema	764	875	870	844	866	509	447	-41%
Dakar	403	402	544	574	664	700	939	133%
Conakry	46	128	85	91	81	93	91	98%
Cotonou	1242	2041	2474	2849	3414	3248	3886	213%
Lomé	1095	1221	1394	1862	2093	1814	2357	115%
Total	**4080**	**5429**	**6369**	**7498**	**8134**	**7622**	**8758**	**115%**

Source: Lihoussou, M. (2014:102).

To be competitive, port authorities or experts must define the frameworks that can accommodate ships and cargo in good condition and in a safe place. Imorou, Dandjeso, Allagbé (2022: 183), studied the relative competition of ports according to the selection criteria. To this end, they defined 12 selection criteria, namely: the geographical location of the port, the socio-political stability of the country, the safety and security of the port, the nautical capacity of the port, the port facilities and equipment, frequency of ship calls, vessel processing time, frequency of cargo handling, port charges, personal connections in the port, facility of customs operations, and good connection of the port with the hinterland. Among the five (Cotonou, Tema, Abidjan, Lomé, Dakar) ports studied, the port of Lomé is the most competitive. The factors determining the selection criteria in the competitiveness of ports are the geographical location of the port; port safety and security; the socio-political stability of the country; and port charges.

2.3. COTONOU PORT AUTHORITY (PORT OF BENIN)

The external environmental impact, the nature of the port authority (autonomy or centralization), the key functions and the agreement with the port operator are the governance factors of a port (Tijan, 2021: 9). The World Bank classified port governance models into four groups. These are the public service port, the private port, the tool port and the landlord port.

Table 6: Basic Port Management Models

Type	Infrastructure	Superstructure	Port labor	Other functions
Public service port	Public	Public	Public	Majority private
Tool port	Public	Public	Private	Public/Private
Landlord port	Public	Private	Private	Public/Private
Private	Private	Private	Private	Majority public

Source: Ago; Yang; Enam (2016).

Port Authority is generally a public enterprise endowed with legal personality and benefiting from management autonomy. It performs multiple functions: Port Authority performs the function of controlling navigation and passengers or goods. It ensures the function of landlord of their maritime space or not. In the case of the owner, the Port Authority concentrates on the rental of the domain. This type of function is illustrated in British ports. It also performs the tooling and operator function. For this type of port, the responsibility for port facilities lies with the State or a local or regional authority. For this, the State or the regional authority finances the construction of port facilities such as quays for terminals. The state (or local or regional authority) can also exploit the tools and terminals itself (example of French and African ports). But in recent times, many African ports like Cotonou Port Authority has entrusted the operation and management of facilities to private port operator. Then, the latter, is responsible for the operation and policing, extension and improvement of the port.

2.3.1. Presentation of Cotonou Port Authority

Located on the Gulf of Guinea and covering an area of 120 kilometers (DED, 2004: 15), the Republic of Benin is a country in West Africa. Since 1965, the Republic of Benin has had a single seaport which is ‘’the lung of the national economy’’. The port handles 90 % of Benin's foreign trade, generates more than 60 % of its GDP, contributes between 45% and 50% of tax revenue and constitutes the main source of customs revenue (80%).

Located along the sandy coast of the Atlantic Ocean on the southern edge of the city of Cotonou, the Port of Benin is delimited between the parallels 6011' 22' North latitude and 2026'30' East longitude. It has the following characteristics (MIT, 2017):

- ❖ Port area of approximately 100 ha;
- ❖ body of water 60 ha;
- ❖ Stores and warehouses of more than 100 000 m^2;
- ❖ 11 berths for all types of vessels;
- ❖ Earth platform (Medians) covered with 150 000 m^2;
- ❖ Used vehicle storage areas of 100 ha;
- ❖ Free zone for Niger, Mali, Burkina-Faso, and Chad;
- ❖ Container yards of 120 000 m^2.

Figure 9: Port of Benin

Source: Imorou, Dandjesso, Allagbé (2022).

Due to geographical position, the Cotonou Port Authority (PAC) attracts cargo bound for land-locked neighbors such as Burkina Faso, Niger, and Mali, as well as for its wealthier neighbor Nigeria and also represents the port of transit and transshipment of Nigerian and Togolese ports. Ports with dynamic and organized hinterlands are more important. Thus, these countries are distant from the port of Benin by:

- 141 km from Ansongo (Mali);
- 1058 km from Niamey (Niger);
- 801 km from N'Gourma (Burkina-Faso);
- 115 km from Lagos (Nigeria);
- 135 km from Lome (Togo).

The Port Authority of Cotonou performs three main functions:

- The commercial function: Engages in the sale and promotion of the port;
- The infrastructure function: Ensures the realization of new works, maintenance, and dredging of quays and nautical accesses;
- The operating function includes the harbormaster's office and the port operations police (i.e. the piloting, towing, and mooring service).

In addition to these functions provided, administrative services are also involved in the management:

- Merchant Navy Department which acts as a manager and controller of seafarers, dangerous goods, and ship safety;
- Police office which maintains security in the port
- Customs office which is responsible for controlling and collecting duties and taxes on goods;
- Health, agriculture, and fishing services are responsible for sanitary, veterinary, and phytosanitary controls. (PAC, 2020: 19; PAC, 2017: 15).

2.3.2. Management of Cotonou Port Authority

Since its creation in 1965, the Port of Benin has remained an industrial and commercial company endowed with legal personality and financial autonomy. Since then, it has always been headed by a Director-General appointed by the government. However, since 2016, the new elected government has had as vision to make the Cotonou Port Authority not only the most competitive logistics platform in the West African sub-region but also the main contributor to the national budget. To achieve this vision, the government called on the expertise of the international port of Antwerp. Thus, since January 2018, a ten (10) year contract has been signed between the government of Benin and the Belgian port of Antwerp. The contract consists of managing the whole logistics platform. The contract content is one year of the approach phase; three (03) years for installation and three (03) years for the execution of project renewal only once.

The Contract linking the two ports consists of the modernization of infrastructures, the organization of the port enclosure, the strengthening of the capacity of local technicians, and the computerization of the port system. With the experience gained in the Ivory Coast (Port of San Pedro), although the objectives are different compared to those of Benin, the International Port of Antwerp (IPA) masters investment methods in Africa. IPA has already started the renewal of infrastructures and superstructures of Benin port. The following table provides information on the first activities executed by the IPA at the port of Benin.

Table 7: Activities and Modernization of Infrastructures

Activities	Sites concerned
Extension of the port basin by 154 m to the West	Port platform
Relocation of the East crossing and extension of the East port basin.	Port platform
Construction of centralized access in the west of the port.	Marina road- Port platform
Construction of a buffer car park in Zongo.	Zongo (Cotonou)
Acquisition of two trailers.	Port platform

Source: Tcheinti-Nabine et Jacob (2021 : 76).

2.3.3. Infrastructures and Superstructures of Cotonou Port Authority

The port of Benin has an access structure 4500 m long and 200 m wide, dredged at a depth of 15 m, allowing the passage of ships to the quays and operating in calm waters (PAC, 2017: 22-23).

Figure 10: Disposition of Terminals at the PAC

1-General cargo pier.
2-RoRo pier.
3-North Container Terminal
4-Easter Jetty P2 and QC (SONACOP oil, clinker, and reefer vessel jetty).
5- ORYX
6-South Container Terminal.

Source: Google image.

- ❖ Strategically located in the North of the port, the integrated commercial quay in a diaphragm wall of 660 m and a draft of -11 m hydro, has eight (08) berths with a total length of 1260 m:
  - The berths Q1, Q2, Q3, and Q4 (155 m long each) and those Q5 and Q6 (180 m long each) are operated for conventional ships;

- The Berths Q7 (220m long) and Q8 (berth at the western end of the quay) are respectively operated for container ships and Ro-Ro ships;
- The berth Q8 initially intended for fishing, is also used by the navy for port service equipment and trawlers.

❖ In the southern zone of the port, an oil berth of the ORYX Company, established in 1997 by the government of Benin, has a length of 250 m and a draft of -11 m.

❖ On the South quay, two berths 546 m long and -15 m draft are allocated to the Bolloré transport-logistics group.

❖ An oil berth with a characteristic of 200 m long and 10 m draft, allows the connection to the general depot via the pipeline of hydrocarbons situated outside the port area. It also allows the unloading of clinkers and gypsum products.

❖ A 160 m of berth for loading oils in bulk is connected by pipeline to a storage depot located in the city.

❖ An additional berth of 100 m long is intended for low tonnage vessels and trawlers on port call or under repair.

❖ Finally, a fishing port.

2.3.4. Handling Terminals Companies of Benin Port

The port of Benin has several terminals that can accommodate ships transporting goods regardless of their nature. The port authorities of Benin are leasing to handling companies, storage areas for containers and Ro-Ro (roll-on/roll-off). Handling companies that operate on the terminals agree to respect the following standards prescribed by the port authorities:

➢ Application of the handling rate or container movement defined for each type of vessel;

➢ Making rational use of leased space;

➢ Frequently sending reports of operations carried out at the terminal, specifying the name of the ship, the ship-owner, the consignee, the berth, dates and times of berthing of ships, date and time of the start of loading/ unloading, date and time of sailing ships, net operating time, idle time, number of movements, number of containers (20' or 40'), equipment productivity (mobile crane, on-board crane, gantry on rails), and an average dwell time of containers on the yards;

- Providing goods nature, tonnage, and handling rates by the bulk and conventional operators.

2.3.4.1. Oil Terminal

An oil terminal is an industrial facility intended for the storage of petroleum and petrochemical products. It is composed of tanks that can be installed above or below ground and a set of valves and meters in order to unload tankers, transport the tanks, and load tank trucks, barges, specialized trains, and pipelines (MediaWikiTest, 2016).

The ORYX Benin Company of the ORYX/ADDAX group, specializing in oil and gas, has an oil terminal located in the south of the port dock. This terminal has a long quay (250 m) and a draft (11 m) and can accommodate vessels with up to 109 m LOA. The terminal capacity is about 55. 000 m^3 for seven (07) storage tanks; and a liquefied petroleum gas (LPG) containing 3. 000 m^3 sphere and 200 m^3 cigar. In addition, the National Company for the Marketing of Petroleum Products (SONACOP) has connection facilities to the port. Thus, unloading rates of Connection of white good to gate 2 and black good to platform C are 500 m^3 and 350 m^3 respectively. Unloading pressures are 7.5 bars for white goods and 5 bars for black goods, with pipeline lengths of 2800 m and 450 m respectively (PAC, 2017).

Figure 11: Oil Terminal at PAC

a- Installation at ORYX terminal.

b- SONACOP connection installation.

Source: Google image.

2.3.4.2. RO-RO Terminal

Ro-Ro terminals are specialized for handling motor vehicles, trucks, tractors, trailers, and other rolling stock. Much easier to handle, these types of cargo are unloaded or loaded from ship to shore (shore to board) on the wheels using ramps or with handling equipment to take the trailers on which the goods are placed (Vadlamudi, 2016: 1). Ro-Ro terminals are the buffer yard type. Two companies are in charge of handling rolling stock at the port of Benin: the Benin port handling company (SOBEMAP), which is a government company, and the Ro-Ro Benin terminal of the GRIMALDI group. Their activities focus on unloading operations of second-hand vehicles from Europe, America, Asia, etc. SOBEMAP and GRIMALDI concede unique buffer parks for grouping second-hand vehicles in a 200 m strip (with an area of 5 ha) and a 300 m strip (with an area of 43. 000 m^2) respectively (PAC, 2017).

Figure 12: RO-RO Terminal at PAC

Source: PAC, 2017: 66.

2.3.4.3. Containers and Yards Terminals

A container terminal is a port infrastructure allowing the operation of container ships. It generally consists of a dock with a draft, a quay for mooring, gantries, cranes, and straddle carriers, stacking spaces for containers, and transporting networks linking inter-modality (road and tracks). Container yards are areas where full or empty containers are kept pending and stripped. Customers or owners of goods have up to eight (08) days to remove their cargos from the yard for Benin destination or the land-locked neighbors and fifteen (15) days for Nigeria. After these periods, goods are subjected to taxes or fees (d'Almeida, 2009).

In Benin, three companies are operating at container terminals:

SOBEMAP is a government company that handles containers and operates loading and unloading activities on the North commercial wharf. It was created in 1969 and held a monopoly until 1998 before being liberalized due to the increasing of container traffic and difficulties. Thus, approval was given to the other two companies. SOBEMAP has an area of 67. 244 m^2 of container storage inside the port (PAC, 2017).

Benin Terminal (BT): is a subsidiary of the Bolloré group, with a terminal at the south quay with a total length of 546 m and a draft that varies between 13.5 m and 15 m. Terminal concession allows to accommodate ships of the WAFMAX and AFRICAMAX. Equipped with four (04) quay gantries (02 KALMAR brand and 02

ZPMC brand), with a capacity of 60 MT and a span of 47 m, and two (02) mobile cranes of 60 MT with a 40 m span, the container operating or storage capacity is 2831 TEUs and 480 refrigerated container sockets. The storage space for full and empty BT containers is 29.5 ha (Amoussa, 2021: 7).

Figure 13: Operation at the BT

Source: PAC, 2017.

APM Terminal: is a concession of the MAERSK group and Cotonou Handling Company S.A. (COMAN S.A). In 1998, the COMAN S.A. terminal was set up and was in charge of container handling operations on behalf of MAERSK. But, since 2010, COMAN S.A. in partnership with the MAERSK group, a Danish subsidiary, has conceded all its container handling operations to the APM terminal of the MAERSK group. MAERSK Group operates 24/7 and has an annual theoretical capacity of 300,000 TEUs. Strategically, APM terminal operations are based in the North of commercial quay. It operates with five (05) mobile port cranes with a lifting capacity of 144 tons.

Figure 14: APM Terminal in Benin

a-Container yard b-Terminal

Source: Google image.

2.3.4.4. Conventional Terminal

Conventional terminal is specialized in handling general cargo i.e. solid bulk cargo. For instance, the miscellaneous and bulk products operated on this terminal are cereals, construction materials, fertilizers, lubricants, clinker, gypsum, etc.

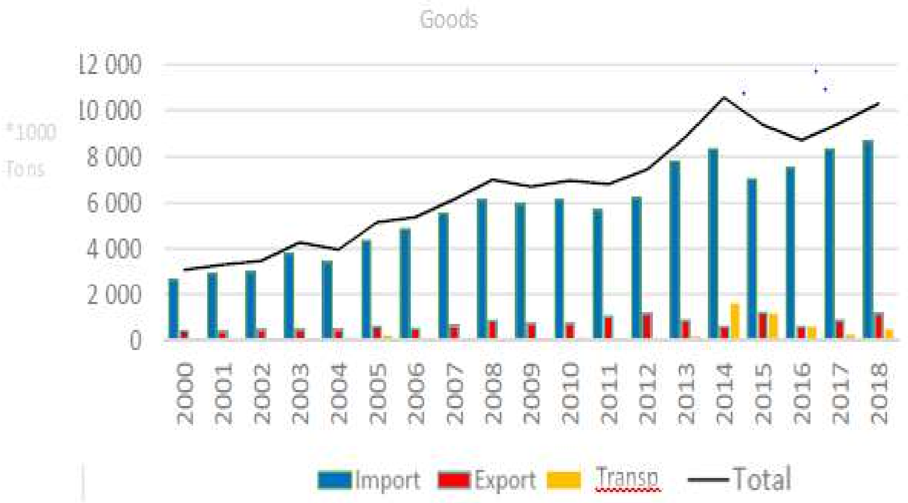
2.4. BENIN PORT PERFORMANCES

2.4.1 Evolution of Traffic

The figure below shows respectively the goods (export, import, and transshipment) handled from 2000 to 2018 at the port of Benin and the destination share of the traffic. In 2018, 10.3 million tons of goods were handled. Imported cargo represents 88%, and those exported are 1.1 million tons. The majority of products imported by the port of Benin are containers, rice, fertilizers, petroleum products, vegetable oil, cement, etc. Exported goods are cotton, cashew nuts, shea butter, cotton seeds, etc. Among imported goods, container cargos are the most handled in Benin port. Thus, after containers (53%) come miscellaneous goods (23%), liquid bulk (13%), dry bulk (9%), and Ro-Ro (2%) respectively (PAC, 2019: 10). The rank that occupied containers in terms of the volume shows that particular interest must be paid to container handling operations (UNCTAD, 2016: 16).

Benin, due to its geographical position, has a great asset. Moreover, among the imported products, 51% are destined for Benin, 37% for Niger, 5% for Nigeria, 4% for Burkina-Faso, and 3% for Mali. With this large number of volumes transiting through the port of Benin for the destination of Niger, the port of Benin is instinctively recognized as the port of Niger (PAC, 2019).

Figure 15: Goods Transported at Benin Port



Source: PAC, 2019: 10.

2.4.2. Waiting Time of Ships

Vessel waiting times are expressed in hours and share of waiting times in percentage. The graphs 16-a compare the performance of operations in terms of time between 2020 and 2021. In 2020, the average operating time on a container ship was 20.4 hours while in 2021 it was 25.5 hours. The waiting times for ships in the harbor to be admitted to berth are longer in 2021 than in 2020. Consequently, the share of average waiting times in 2020 (57 %) is categorically lower than in 2021 (60 %). Due to the poor performance, measures to reduce the waiting time have been undertaken through the commitment of the port authorities. Thus, in December 2021, the hours spent in the harbor by container ships were lower.

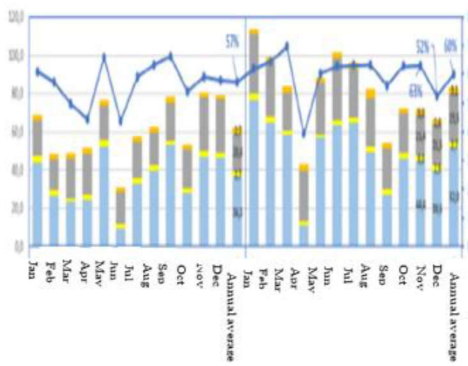
Figure 16-b described the annual average time spent by the conventional vessel in the harbor. In 2020, the annual average time passing by the ship was 29%; and that of 2021, was 38%.

Figure 16-c noted that vehicle carriers spent less time to operate in 2021 than in 2020. Conversely, ships spent more waiting time in the harbor in 2021 (9.1 h) than in 2020 (3.7 h). However, the share of waiting time was higher in 2021 than in 2020. This could be explained by the lack of efficiency in time management.

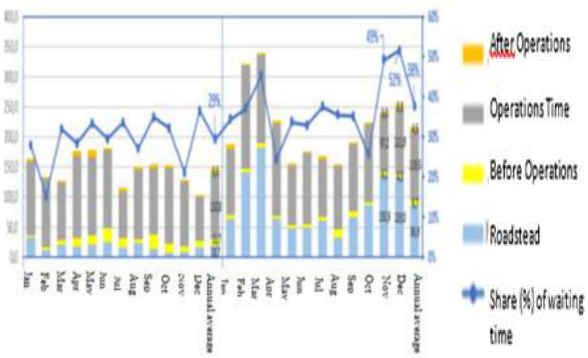
For the figure 16-d, the average waiting time after the operation is higher in 2021 (5.8 h) than in 2020 (5.6 h). In December 2021, the operation post-hours have increased compared to the previous month of the same year. This may be explained by the fact that the terminal connection flexibles were not suitable for the ALITTHINI vessel, which had to wait 34 hours to disconnect it before setting sail.

Figure 16: Waiting Time of Ships at PAC

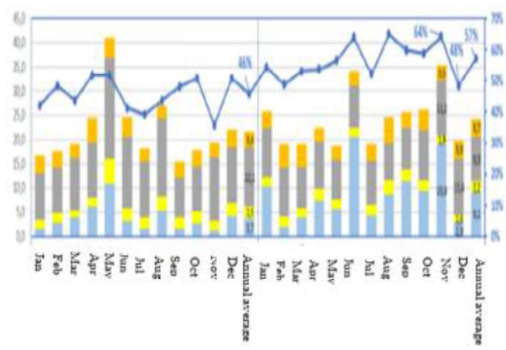
a- Waiting time of container vessel



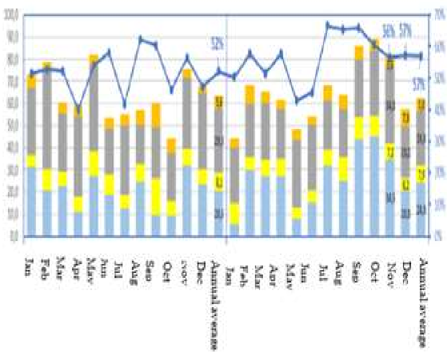
b- Waiting time of conventional vessel



c-Waiting time of vehicle carrier vessel



d-Waiting time of tankers vessel



Source: PAC, monthly report, 2020-2021.

2.4.3. Container Handling and Ships Calls Rate

Table 8 shows the container (20 feet) handling rates from 2013 to 2016. By observing the data relating to the Benin terminal (BT) operations, the number of containers handled per hour decreased gradually in 2014 and 2015, before bouncing back in 2016 (41 containers handled per hour). This number is lower than the technical capacity (50-60/h) and greater than the operational capacity (20-30/h) proposed by Steeken et al, (2004). The BT then has had a remarkable operational capacity over the past few years.

The rate of containers handled in Benin by SOBEMAP is not efficient from a technical and operational point of view because the number shown in the table are below those indicated by the researchers. However, the rate of containers handled per hour by the company COMAN S.A. (APM Terminal) is slightly down but remains efficient from an operational point of view.

Table 8: Container Handling Rate

Years	**2013**	**2014**	**2015**	**2016**
Container handling rate by BT.	32	24	29	41
Container handling rate by SOBEMAP.	18	18	16	16
Container handling rate by COMAN S.A. (APM terminal)	46	36	39	42

Source : MIT, 2017.

Table 9: Number of Ships Calls at the Port of Benin

Type of Ships Year	Non-Commercial Ships	Commercial Ships	Total
2013	255	1154	1409
2014	754	1279	2033
2015	190	1142	1332
2016	24	1031	1055

Source : MIT, 2017.

The number of ships berthed at the port of Benin in 2013, 2015, and 2016 decreased gradually except in 2014. This poor performance observed in Benin is due to the remarkable performance of neighboring port (Togo) which developed its terminal infrastructure. However, in recent years the port of Benin has embarked on a large-scale project to better face sub-regional competition.

CHAPTER THREE
RESEARCH METHODOLOGY

In this part, different methods that make up the methodology of our research, the choice of inputs and outputs, the model-oriented and the mathematical formulas were tackled.

3.1. METHODOLOGY

In the seventy-century, data envelopment analysis (DEA) was developed by researchers Abraham Charnes, William W. Cooper, and Edward Rhodes. Under the designation and abbreviation of the surnames of these researchers, the first method was designated DEA-CCR. The role of the DEA-CCR method is to assess the total efficiency of decision-making units (DMUs) (Seiford and Thrall, 1990: 27). This method is used under the constant return to scale (CRS) assumption. Besides, DEA-CCR, a second DEA-BCC method was completed by Banker-Charnes-Cooper in 1980. This second method consists of distinguishing between technical and scale inefficiency. It is used under the variable return to scale (VRS) assumption. Although the two methods DEA-CCR and DEA-BCC have different orientations, they all deal with managerial and economic questions (Seiford and Thrall, 1990: 27-28).

DEA is a non-parametric deterministic approach that solves standard technical problems of linear programming. Its particularity is to compare all similar organizations in a given population by taking into account various dimensions (Amouzou, 2017). DEA is a benchmarking approach serving as a decision support tool for organizations or companies (Azzelarab, 2018: 219). DEA permits to identify the performance of decision-making units (DMUs). The decision making units that are located above the envelope or the production function are efficient; while those located below the envelope are inefficient.

Compared to other methods, DEA has specific attributes. Gonzalez and Trujillo (2009: 164) defined the characteristics of the DEA as follows:

- Non-parametric approach
- Deterministic approach
- Does not consider random noise

- Does not allow statistical hypothesis to be contrasted
- Does not carry out assumptions on the distribution of the inefficiency term
- Does not include error term
- Does not require specifying functional form
- Sensitive to the number of variables, measurement errors and outliers
- Estimation method: mathematical programming.

In recent years, DEA method has been frequently adopted to determine the technical efficiency and scale scores regardless of the sector. The adoption of DEA in the maritime sector helped to assess the efficiency scores of the three different container terminals (SOBEMAP, APM terminal, Benin terminal) operating at the port of Cotonou. The scores permitted to do benchmarking between the three companies. Terminals whose efficiency scores were equal to 1 were considered efficient.

3.2. DATA COLLECTION

We first had a look at the literature in order to have enough backgrounds and types of data that applied to our study. Thus, based on the documentation, we were interested in the data contained in the statistical yearbook and the activity reports of the container terminals of Cotonou port authority. To access the data, we signed a confidential letter and non-disclosure data commitment (**Appendix 1**) provided by the port authorities of Benin.

After signing, we only considered the statistical data from 2016 to 2021 to study the efficiency of CTs. This period was chosen because it referred to the first term of the current government; and it is known that the management of the port is government policy-depended. However, due to Covid-19, data related to year 2021 was not yet available. Thus, we focused on statistical data from 2016 to 2020. Data over a long period or panel are more consistent for estimating performance with the mathematical programming technique than the cross-sectional data (single-year period) (Wang, Song, Cullinane, 2003).

3.3. SAMPLING

Variable data, summarizing into two (outputs and inputs) was collected. Data selection respected certain criteria previously defined by (Cooper, 2007: 22):

- The data must be numeric and positive;
- The items (inputs, outputs, and choice of DMUs) should reflect an analyst's or a manager's interest in the components that will enter into the relative efficiency evaluations of the DMUs;
- The data chosen for the inputs must be of small value, and high value for the outputs;
- Units of measurement for input and output values do not need to be consistent. For example, some values are expressed in a number of people, in space (ha), in units of currency, etc.

3.3.1. Selection of Output

In several previous studies, the outputs generally used for the calculation of efficiency scores of container ports were number of containers, tonnage of goods, call of ships, etc. In our study, we focused on the total number of containers in TEU handled at the three container terminals as a single output. The data obtained from each terminal handling company were provided beforehand in percentage that we converted into a numerical value. Decimal digits are rounded up and calculated data is shown in the following table:

Table 10: Containers-TEU

Total number of containers (in TEUs) handled by CTs companies at the PAC.					
	2016	**2017**	**2018**	**2019**	**2020**
SOBEMAP (CT1)	7 496	7 557	9 304	5 272	11 437
APM TERMINAL (CT2)	171 168	108 309	168 739	88 907	65 071
BENIN TERMINAL (CT3)	133 686	164 003	244 862	145 462	317 860
TOTAL	312 350	279 869	422 905	239 641	394 368

Source: PAC-Statistics Yearbook.

3.3.2. Selection of Inputs

Four inputs storage area, RTG, Quay length, and Quay crane regularly found in the literature, were chosen. The consistency of these inputs is proved by the fact that they influence directly container terminal handling operations. In addition, there is an impact of capital investments by terminal promoters on the acquisition of engines and the construction of terminal infrastructure (e.g. quays, tank yards, hangars, etc.) (Quansah, 2008: 37). Input data related to storage space was initially collected in units of square meters (m^2). Since the values of the inputs had to be small compared to the outputs (Cooper, 2007), we converted data from meters-square (m^2) into hectare (ha) to have small values. Table 11 and 12 define respectively the characteristics and the data of inputs.

Table 11: Specification of Input Variables

Variables	
Inputs	Quay crane (Numbers)
	RTG -Yard crane (Numbers)
	Storage area (ha)
	Quay length (Meters)

Source: Author

Table 12: Inputs Values

	Variables			
	Quay crane (N)	**RTG (N)**	**Storage area (ha)**	**Quay length (m)**
SOBEMAP	00	00	17.94	220
APM TERMINAL	05	00	16.84	220
BENIN TERMINAL	06	12	52.90	546

Source: PAC-Statistics Yearbook.

3.4. ORIENTATION OF THE MODEL AND COMPUTER PROCESSING TOOL

Cotonou Port Authority aims to maximize the number of containers handled (throughput) by the container terminal operators with the resources available and therefore be able to compete with other ports in the West African sub-region. Operators of handling companies with limited resources (inputs), for the facilitation of operations on the terminal, are obliged to improve their performance according to the available resources. Generally, the orientations are done according to two models (either by output or input). The input-oriented model consists of minimizing the number of inputs (storage space, length of the dock, RTG, for example) while keeping the level of output invariable. Likewise, output-oriented maximizes the number of outputs (containers) while keeping the level of input constant (Panayides et al., 2008: 5). At the PAC, terminal operators are often confronted with sufficient resources, and work with their policy to increase productivity. Thus, we oriented our model according to the output. The policy was to keep our limited resources (input) unchangeable, and through the performance of the terminals increasing the number of containers. Finally, the efficiency of each company was checked.

Software DEA Program (DEAP) was used to run the data. Then, we opted for two-stage DEA and the constraint under the VRS assumption to obtain all the technical and scale scores.

3.5. MATHEMATICAL FORMULATION

Container terminals such as SOBEMAP (CT1), APM terminal (CT2), and Benin terminal (CT3) operating at the port of Cotonou are considered as decision-making units in this study. Each decision making unit (DMU) handles some containers while using resources allocated to handling operations. This number of containers operated is represented as output and the resources used to operate are considered as inputs in this study. This output is denoted by Y in linear programming, and X is the input. The ratio between the sum of the output weights and that of the input weights determines the efficiency of the decision units. In addition, the value from the efficiency score must be less than or equal to 1 (Charnes et al., 1978: 430). The ratio maximization formula can be summarized as follows:

Equation (1):

$$\text{Max } \Theta_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1; \qquad j = 1, \ldots, n.$$

$$u_r, v_i \geq 0 ; \quad r = 1,…., s; \quad i= 1,….., m.$$

Keeping the framework of the study of the performance of the terminals, we denote by:

Max θ_o: maximum ratio (technical efficiency) of weighted output to weighted input.

y_{rj} : amount of output "r" produced by terminal j.

x_{ij} : amount of input "i" used by terminal j.

u_r = coefficient or weight assigned by DEA to output "r".

v_i = coefficient or weight assigned by DEA to input "i".

s: amount of output.

m: amount of input.

To solve equation (1), we transform it into a linear programming equation.

Equation (2):

$$\max \sum_{r=1}^{s} u_r\, y_{ro}$$

$$\sum_{i=1}^{m} v_i x_{io}=1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 ; \quad j= 1, ……., n.$$

$$u_r, v_i \geq 0$$

To solve equation (2), primary and dual forms were formulated according to the CCR (constant return to scale-CRS) model. Based on the output-oriented model (maximizing containers while keeping or minimizing the number of resources stable) equation (3) is described as:

- Primary form:

$$\min \theta = \sum_{i=1}^{m} v_i x_{io}$$

Subjct to:

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \geq 0$$

$$\sum_{r=1}^{s} u_r\, y_{ro} = 1$$

$$u_r, v_i \geq 0$$

- Dual form:

$$\max \theta$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} \lambda_j - x_{io} \leq 0 , \quad i= 1, …., m.$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - \square y_{ro} \geq 0 , \quad r= 1, \ldots, s.$$

$$\lambda_j \geq 0 ; \quad j= 1, \ldots, n.$$

The development of CCR in 1978 by Charnes, Cooper, Rhodes; and BCC (Variable return to scale-VRS) model initiated by Banker et al. (1984) with the addition of new constraints demonstrated that not all decision units (terminals) operate at an optimal scale (Kalgora et al., 2019). Thus, the full equation (4) of BCC is:

- Primary form:

$$\min \Theta = \sum_{i=1}^{m} v_i x_{io} - v_o$$

Subjct to:

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} - v_o \geq 0$$

$$\sum_{r=1}^{s} u_r\, y_{ro} = 1$$

$$u_r, v_i \geq 0; \; v_o \text{ free in sign.}$$

- Dual form:

$$\max \Theta$$

Subject to :

$$\sum_{j=1}^{n} x_{ij}\lambda_j - x_{io} \leq 0 , \quad i= 1, \ldots, m.$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - \square y_{ro} \geq 0 , \quad r= 1, \ldots, s.$$

$$\sum_{j=1}^{n} \lambda_j = 1.$$

$$\lambda_j \geq 0 ; \quad j= 1, \ldots, n.$$

- λ_j: Weighting linked to the inputs and outputs of the DMUj.

The calculation of the scale efficiency coefficient (SE) was determined based on the results obtained from the coefficients of the BCC and CCR models. It's the ratio between the CRS and VRS coefficients. Thus, we have:

$$SE = \frac{CRS\ (CCR)}{VRS\ (BCC)}$$

CHAPTER FOUR

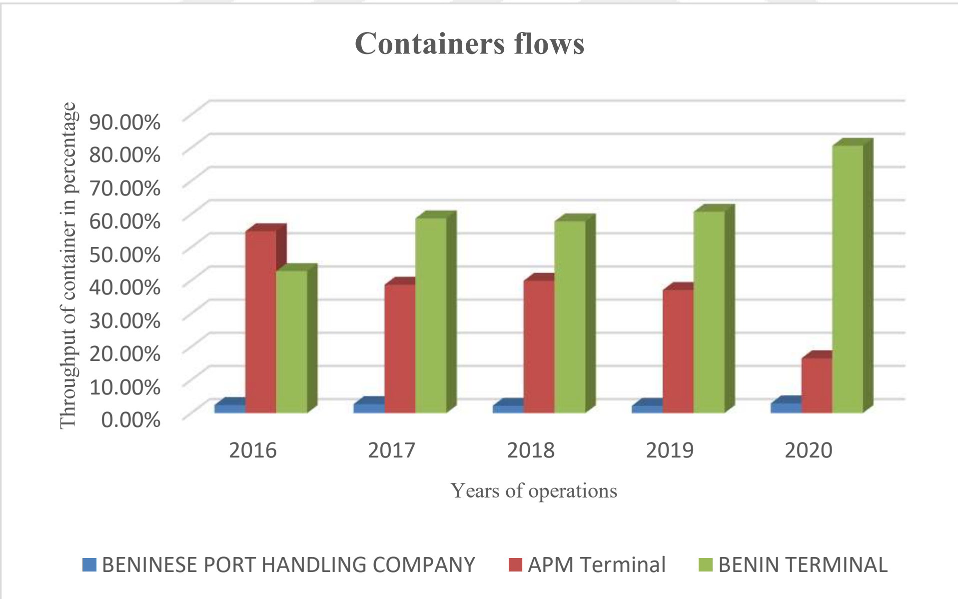
RESULTS, DISCUSSION, AND RECOMMENDATIONS AND LIMITATIONS OF THE RESEARCH

In this chapter, the descriptive analysis, the results and interpretations, discussion, and the recommendations and research limitation part were presented.

4.1. DESCRIPTIVE ANALYSIS

Based on the container traffic data (TEU) collected, we made for the five years (2016-2020) a 3-band histogram. Except for 2016, where APM Terminal operated more containers than others, the Benin Terminal company of the French group (Bolloré) had a higher operating capacity than the other companies between 2017 and 2020.

Figure 17: Container Flow at PAC



Source: Author.

Information related to the average, maximum, minimum, and standard deviation of container flows (throughput) of the three handling companies (SOBEMAP, APM Terminal, Benin Terminal) over the five years were summarized in table 13. Over five years, SOBEMAP (CT1) handled an average of 8213.2 containers (TEU) with a quay linear of 220 m, a storage capacity of 17.94 ha, 0 yard crane (RTG), and 0 quay gantry crane. On the average, the APM Terminal (CT2) operated 120438.8 containers with stable inputs of 220 linear meters of quay, 0 yard crane, 5 mobile gantry cranes, and a storage capacity of 16.84 ha. Finally, in five years, on the average, the Benin Terminal (CT3) carried out container loading/unloading operations at '201174.6' per year. The unchangeable resources allocated to these operations were 12 yard gantries (RTG), a linear quay of 546 m, 6 gantry cranes, and a storage capacity of 52.90 ha.

Table 13: Descriptive Statistics of CTs

Statistics data 2016-2020	**CT1-Throughput**	**CT2-Throughput**	**CT3-Throughput**
N. of observations	5	5	5
Minimum	5272	65071	133686
Maximum	11437	171168	317860
Means	8213.2	120438.8	201174.6
S. Deviation	2300.9	47731.9	78365.2

Table 14 presents the correlation coefficients between inputs and outputs by year. In 2016, among terminal inputs, gantry cranes showed a strong correlation with output, followed by yard gantries and quay length and storage capacity. In 2017, 2018, and 2019, the strongest link between quay cranes and the output (container) was observed. The prevalence correlation coefficients for the three years were 0.98; 0.99 and 0.97 respectively. In addition, input quay cranes were followed by yard cranes, length of the quay, and storage capacity. In 2020, the yard crane (0.99) and quay linear (0.99) input were strongly correlated with outputs; followed by storage capacity and gantry cranes.

Table 14: Pearson Coefficient

Outputs by year ⇒ Inputs ⇓	**Proximity matrix (Pearson correlation coefficient).**				
	2016	**2017**	**2018**	**2019**	**2020**
Quay crane	**0.93**	**0.98**	**0.99**	**0.97**	**0.75**
RTG -Yard crane	**0.29**	**0.77**	**0.75**	**0.81**	**0.99**
Storage area	**0.27**	**0.75**	**0.73**	**0.79**	**0.98**
Quay length	**0.29**	**0.77**	**0.75**	**0.81**	**0.99**

4.2. RESULTS AND INTERPRETATIONS

The results of TE and SE are crucial in determining organizations' performance. The result of TE allowed to interpret results related to the planning, strategy, managerial, and economic management of companies, while the result of SE led to scaling interpretation of optimal size. Analysis was under the assumption of return-to-scale variables (VRS) and output-oriented.

Table 15 shows the results of the DEA-method analysis over five years.

Table 15: Efficiencies Score of CTs

Years	Containers Terminals	Technical efficiency (TE)		Scales efficiency (SE)	Nature of returns to scale
		CRS (CCR)	VRS (BCC)		
2016	CT1	1.00	1.00	1.00	-
	CT2	1.00	1.00	1.00	-
	CT3	0.62	0.78	0.79	DRS
2017	CT1	1.00	1.00	1.00	-
	CT2	1.00	1.00	1.00	-
	CT3	1.00	1.00	1.00	-
2018	CT1	1.00	1.00	1.00	-
	CT2	1.00	1.00	1.00	-
	CT3	1.00	1.00	1.00	-
2019	CT1	1.00	1.00	1.00	-
	CT2	1.00	1.00	1.00	-
	CT3	1.00	1.00	1.00	-
2020	CT1	1.00	1.00	1.00	-
	CT2	1.00	1.00	1.00	-
	CT3	1.00	1.00	1.00	-
Average efficiency scores (2016-2020)	CT1	1.00	1.00	1.00	
	CT2	1.00	1.00	1.00	
	CT3	0.92	0.96	0.96	

Scale efficiency (SE) = CRS/VRS (-): Constant return to scale. (Drs): decrease return to scale.

In 2016, the CT1 and CT2 terminals were efficient with the CCR (CRS) and BCC (VRS) models which efficiency scores were equal to 1. Consequently, CT1 and CT2 demonstrated the best practice frontier. But in the case of CT3, for both models, the efficiency score was less than 1. The technical scores of CRS and VRS were 0.622 and 0.781 respectively. So, the CT3 is not at its best practice frontier. Regarding the scale efficiency result, CT1 and CT2 were also efficient with efficiency scores equal to 1; indicating that CT1 and CT2 operated at the optimal size of constant return to scale and CT3 at decreasing return to scale. For CT3, the score was 0.796.

Regarding the nature of the return to scale, the terminals (CT1 and CT2) presenting results in dashes (-) showed that the variation of production of 1% of output was proportional to the consumption of resources (inputs) of 1%. Thus, no effect on the operational scale situation was observed. The CT3 terminal associated with DRS (decreasing return scale) operated with a decrease returns to scale. CT3 was able to project its production up to 171,168,000 TEU containers with a radial movement of 37,482,000. Also, a slack movement with inputs was observed (table 16). CT3 to be efficient, must have its inputs reduced. Input 1 (gantry cranes) must be reduced by (-1.00), i.e. 5 gantry cranes would have been the maximum number to use. Input 2 presents a slack movement of (-12), i.e. the use of yard cranes was not necessary. Input 3 also showed a slack on the frontier of (-36.060); indicating that the optimal size of terminal or yard storage space (52.9-36.060) needed was 16,840 ha. Finally, at the input 4 level, we observed a slack movement of (-326), i.e., the maximum size of linear quay to be used by the Benin terminal to be efficient was 220 m.

Table 16: Projection Summary

Variable		Original value	Radial movement	Slack movement	Projected value
Output	1	133686.000	37482.000	0.000	171168.000
Input	1	6.000	0.000	-1.000	5.000
Input	2	12.000	0.000	-12.000	0.000
Input	3	52.900	0.000	-36.060	16.840
Input	4	546.000	0.000	-326.000	220.000

In 2017, the technical efficiency calculated on the basis of the CRS and VRS models presented scores equal to 1 for the three terminals CT1, CT2, and CT3. We concluded that the three terminals were efficient and had a good performance at the managerial level. The scale efficiency scores for the three terminals were also equal to 1. Therefore, the three terminals operated at the optimal size of the constant return scale. No inappropriate operational scale effect was noted regarding results related to the nature of returns to scale.

Table 15 also provides information on the technical efficiency and scale scores for the year 2018. Results confirmed that based on managerial and economy of scale, the three terminals are efficient. The efficiency scores associated with the decision units were all equal to 1. Regarding the nature of scale efficiency, no inappropriate operational scale impact was observed even though the use of outputs increases proportionally with the inputs consumed. Thus, a production of 1 % containers used an average of 1 % of allocated resources.

The results of the analysis of technical efficiency scores and scales in 2019 showed that the terminals performed at 100 % whether at the technical level or scale. Regarding the nature of the return to scale, the terminals ensured their productivity without decreasing or increasing the level of efficiency while keeping the inputs stable.

In 2020, the technical (CRS and VRS) and scale efficiencies of CT1, CT2, and CT2 reached 100 %. They operated with a constant return to scale. Therefore, the production of a unit of output varied in the same proportion with the allocated resources.

4.3. DISCUSSION

Overall, the three container terminals of Cotonou Port Authority studied presented satisfactory performance. The best performance achieved by the container terminals during the five consecutive years (except for the result of CT3 in 2016) is due to the reforms carried out at the port by the actual government since its accession to power in 2016. This government aiming to make the Cotonou Port Authority more competitive in the West African region, made a reorganization of the whole management structure of the port. Therefore, the management was entrusted to experts of the Port of Antwerp. The policy of structural reorganization and investment (acquisition of equipment, expansion of parks, etc.) in the port has enabled to change the methods of operation of stevedores in order to achieve the expected performance. This raised the performance ranking of the port of Benin in terms of the amount of operations time and logistics performance in the port compared to other regional ports e.g. Lomé (Togo), Lagos (Nigeria), Tema (Ghana), and Abidjan (Ivory Coast) (Banque mondiale, 2021).

Nevertheless, in 2016 on the CT3, we noted the inefficiency of technical and scale. This result may be due to the change in the political plan as stated by Barros et al. (2010). The authors reported that reform policy adopted by the government towards ports can have an impact on the performance of the container seaport. Similar results were observed in the Ivory Coast due to political instability (Carine, 2015). This inefficiency can also be explained by repeated maritime piracy in the waters of the Gulf of Guinea during this period, thus preventing ships from sailing freely to dock on the West African coast; especially at PAC. Because we noticed that the CT3 had overused the capacity of its resources (inputs) regarding the number of available containers.

Moreover, the governance in the previous time by the Benin port authorities had shown only negative results. The difference in port performance between previous studies and our study on port was very noticeable. Despite the inefficiency observed in 2016, the performance under the new government was more effective compared to that from former government. For example, the current container seaport of Cotonou studied was technically and scale efficient compared to the previous studies by Kalgora et al., (2009) and Carine (2015). In addition, studies of 16 container ports in sub-Saharan Africa showed that the container seaports in Benin (compared to others African container seaports) had an insignificant scale and technical efficiency (Van Dyck, 2015).

4.4. RECOMMENDATIONS AND RESEARCH LIMITATIONS

For the container terminals of Cotonou Port Authority, either public or private, to be efficient, several measures must be taken by the port authorities and the container seaports operators:

- The port authorities must adopt reforms that give the same chance of operation (loading/unloading of containers) to all companies;
- The government must take advantage of its public-private partnership to train quality technicians on the terminals;
- As SOBEMAP is a State structure, the government must vote on budgets that can help it to acquire resources (inputs), allowing operations on CTs instead of renting from other companies. For example, acquiring its gantry cranes, quay cranes, yard cranes, lifting equipment, etc. would be better;
- The Beninese government through the public-private partnership must build infrastructure like a special terminals for each handling company to the detriment of sharing post/quay 8 between SOBEMAP and APM terminal. This would help them to be more performants;
- Terminal management operators (stevedores) must ensure that the handling rates required by the authorities are applied so that container port entities are technically or operationally efficient;
- Operators must plan a short operating route on the quay-yard in order to use resources (inputs) efficiently for handling the corresponding number of containers in record time;
- Regular monitoring must be made by the port authorities to bring the stevedores to follow the roadmap;

Academically:

- Further research must extend our study to a period of ten years or more; evaluate the allocative efficiency; and use other methods to determine the performance of container ports like SFA (Stochastic Frontier Analysis), Malmquist, etc.

This dissertation faced some limitations. The main limitations were related to the data. By submitting the request to access data (Appendix 1) at the port of Cotonou, we were confronted with the possession of all the desired data. Because, our goal was to extend the data until 2021, in order to devote the study to the first term of the current government. But due to Covid-19, not all data was recorded in the statistical file. We also had difficulty with resource (input) data. Like SOBEMAP and APM terminals have the authorization to operate on the same terminal, we had difficulty in differentiating the input data linked to the quay length.

CONCLUSION

The existence of a port environment is identified with the installations, loading/unloading activities carried out by the operators of the terminals with the agreement of the port authorities. Among the terminals, container terminals are freight transit points whose operations are easy to perform. The performance of container terminals is necessary, so its determination is accentuated on its productivity and the ability of handlers to use the operational infrastructures optimally.

In this thesis, our reflection focused on the evaluation of the performance of the different container terminals at Cotonou Port Authority (PAC). To achieve our study's goal, we first approached the literature part which is related to the topic. Next, we applied the research mathematical method that's non-parametric linear programming called DEA which allowed us to determine the technical efficiency, scale efficiency and nature of the return to scale of the three container terminals i.e. Benin Port handling company (SOBEMAP), APM terminal, and Benin terminal. The CCR and BCC model were the two methods used and the data used covered five years 2016-2020. We used a single output (container throughput in TEU) and four inputs (quay cranes, yard cranes, storage area, and quay length).

Generally, all three CTs of the PAC presented a good performance (technical and scale efficiency). But in 2016, we noticed an inefficiency in the CT3. The particularity of this result was due to the reform policy adopted by the Beninese government. To overcome all inefficiency problems, we provided recommendations to port authorities, terminal management operators, and academicians.

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APPENDICES

- S'engager à ne pas divulguer l'Information ;

- Reconnaître que les données écrites sur support papier sont et resteront la propriété du Port Autonome de Cotonou, et que de telles données écrites ne peuvent être copiées ou reproduites sans l'autorisation écrite expresse et préalable du Port Autonome de Cotonou. Les originaux et toutes les copies de telles données écrites devront être restitués dans les 20 jours suivant toute demande du Port Autonome de Cotonou ;

- S'engager à apporter à l'Information tous les soins nécessaires et au minimum ceux appliqués à ses propres informations ayant une importance équivalente, de manière à éviter une publication, une divulgation non-autorisée de l'Information, ou un usage de celle-ci autre que celui pour lequel l'information a été demandée ;

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Par ailleurs

- Toute Information divulguée et communiquée demeurera la propriété du Port Autonome de Cotonou et lui sera restituée ou détruite au cas où le Port Autonome de Cotonou en ferait la demande, ainsi que les copies faites. Sur demande du Port Autonome de Cotonou je transmettrai au Port Autonome de Cotonou une attestation de destruction ;

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- Toute préoccupation relative au présent Engagement doit faire l'objet d'un courrier recommandé avec accusé de réception au Port Autonome de Cotonou ;

- Cet Engagement s'applique également à toute personne morale (en particulier société, association, filiale, etc.) qui est directement ou indirectement, en fait ou en droit en position de me contrôler ou en position d'être contrôlé par moi ;

- Cet Engagement restera en vigueur durant les 5 (cinq) années à compter de la date effective de sa signature ;

APPENDIX 2: DEA-Results

Year: 2016

```
 Results from DEAP Version 2.1

Instruction file = A16-ins.txt
Data file        = A16-dta.txt

 Output orientated DEA

 Scale assumption: VRS

 Two-stage DEA method

 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

    1  1.000  1.000  1.000  -
    2  1.000  1.000  1.000  -
    3  0.622  0.781  0.796 drs

 mean  0.874  0.927  0.932

Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

 SUMMARY OF OUTPUT SLACKS:

 firm  output:          1
    1               0.000
    2               0.000
    3               0.000

 mean               0.000


 SUMMARY OF INPUT SLACKS:

 firm  input:          1           2           3           4
    1              0.000       0.000       0.000       0.000
    2              0.000       0.000       0.000       0.000
    3              1.000      12.000      36.060     326.000

 mean              0.333       4.000      12.020     108.667
```

```
SUMMARY OF PEERS:

 firm  peers:
   1      1
   2      2
   3      2

SUMMARY OF PEER WEIGHTS:
  (in same order as above)

 firm  peer weights:
   1   1.000
   2   1.000
   3   1.000

PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
   1       0
   2       1
   3       0

SUMMARY OF OUTPUT TARGETS:

firm  output:        1
   1          7496.000
   2        171168.000
   3        171168.000
```

```
SUMMARY OF INPUT TARGETS:

firm  input:          1          2          3          4
  1               0.000      0.000     17.940    220.000
  2               5.000      0.000     16.840    220.000
  3               5.000      0.000     16.840    220.000

FIRM BY FIRM RESULTS:

Results for firm:     1
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)


PROJECTION SUMMARY:
  variable            original      radial       slack    projected
                         value    movement    movement        value
 output     1         7496.000       0.000       0.000     7496.000
 input      1            0.000       0.000       0.000        0.000
 input      2            0.000       0.000       0.000        0.000
 input      3           17.940       0.000       0.000       17.940
 input      4          220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    1       1.000

Results for firm:     2
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable            original      radial       slack    projected
                         value    movement    movement        value
 output     1       171168.000       0.000       0.000   171168.000
 input      1            5.000       0.000       0.000        5.000
 input      2            0.000       0.000       0.000        0.000
 input      3           16.840       0.000       0.000       16.840
 input      4          220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    2       1.000
```

```
Results for firm:     3
Technical efficiency = 0.781
Scale efficiency     = 0.796  (drs)

PROJECTION SUMMARY:
  variable            original       radial        slack     projected
                         value     movement     movement         value
 output      1      133686.000    37482.000        0.000    171168.000
 input       1           6.000        0.000       -1.000         5.000
 input       2          12.000        0.000      -12.000         0.000
 input       3          52.900        0.000      -36.060        16.840
 input       4         546.000        0.000     -326.000       220.000
 LISTING OF PEERS:
  peer   lambda weight
    2      1.000
```

Year : 2017

```
 Results from DEAP Version 2.1

Instruction file = A17-ins.txt
Data file        = A17-dta.txt

 Output orientated DEA

 Scale assumption: VRS

 Two-stage DEA method

 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

    1  1.000  1.000  1.000  -
    2  1.000  1.000  1.000  -
    3  1.000  1.000  1.000  -

 mean  1.000  1.000  1.000

Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

 SUMMARY OF OUTPUT SLACKS:

 firm  output:          1
    1               0.000
    2               0.000
    3               0.000

 mean               0.000


 SUMMARY OF INPUT SLACKS:

 firm  input:          1          2          3          4
    1              0.000      0.000      0.000      0.000
    2              0.000      0.000      0.000      0.000
    3              0.000      0.000      0.000      0.000

 mean              0.000      0.000      0.000      0.000
```

```
SUMMARY OF PEERS:

 firm  peers:
   1      1
   2      2
   3      3

SUMMARY OF PEER WEIGHTS:
  (in same order as above)

 firm  peer weights:
   1    1.000
   2    1.000
   3    1.000

PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
   1        0
   2        0
   3        0


SUMMARY OF OUTPUT TARGETS:

firm  output:            1
   1           7557.000
   2         108309.000
   3         164003.000


SUMMARY OF INPUT TARGETS:

firm  input:          1          2          3          4
  1               0.000      0.000     17.940    220.000
  2               5.000      0.000     16.840    220.000
  3               6.000     12.000     52.900    546.000


FIRM BY FIRM RESULTS:

Results for firm:      1
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable           original      radial       slack    projected
                        value    movement    movement        value
 output     1        7557.000       0.000       0.000     7557.000
 input      1           0.000       0.000       0.000        0.000
 input      2           0.000       0.000       0.000        0.000
 input      3          17.940       0.000       0.000       17.940
 input      4         220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    1      1.000


Results for firm:      2
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable           original      radial       slack    projected
                        value    movement    movement        value
 output     1      108309.000       0.000       0.000   108309.000
 input      1           5.000       0.000       0.000        5.000
 input      2           0.000       0.000       0.000        0.000
 input      3          16.840       0.000       0.000       16.840
 input      4         220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    2      1.000
```

```
Results for firm:     3
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable            original        radial         slack      projected
                         value      movement      movement          value
 output      1      164003.000         0.000         0.000     164003.000
 input       1           6.000         0.000         0.000          6.000
 input       2          12.000         0.000         0.000         12.000
 input       3          52.900         0.000         0.000         52.900
 input       4         546.000         0.000         0.000        546.000
 LISTING OF PEERS:
  peer   lambda weight
    3      1.000
```

Year: 2018

```
 Results from DEAP Version 2.1

Instruction file = A18-ins.txt
Data file         = A18-dta.txt

 Output orientated DEA

 Scale assumption: VRS

 Two-stage DEA method

 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

    1  1.000  1.000  1.000  -
    2  1.000  1.000  1.000  -
    3  1.000  1.000  1.000  -

 mean  1.000  1.000  1.000

Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

 SUMMARY OF OUTPUT SLACKS:

 firm  output:           1
    1              0.000
    2              0.000
    3              0.000

 mean              0.000


 SUMMARY OF INPUT SLACKS:

 firm  input:           1           2           3           4
    1               0.000       0.000       0.000       0.000
    2               0.000       0.000       0.000       0.000
    3               0.000       0.000       0.000       0.000

 mean               0.000       0.000       0.000       0.000
```

```
SUMMARY OF PEERS:

 firm  peers:
   1       1
   2       2
   3       3

SUMMARY OF PEER WEIGHTS:
  (in same order as above)

 firm  peer weights:
   1   1.000
   2   1.000
   3   1.000

PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
   1       0
   2       0
   3       0

SUMMARY OF OUTPUT TARGETS:

firm  output:          1
   1            9304.000
   2          168739.000
   3          244862.000


SUMMARY OF INPUT TARGETS:

firm  input:         1          2          3          4
   1             0.000      0.000     17.940    220.000
   2             5.000      0.000     16.840    220.000
   3             6.000     12.000     52.900    546.000


FIRM BY FIRM RESULTS:

Results for firm:     1
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable           original     radial      slack   projected
                        value   movement   movement       value
 output      1       9304.000      0.000      0.000    9304.000
 input       1          0.000      0.000      0.000       0.000
 input       2          0.000      0.000      0.000       0.000
 input       3         17.940      0.000      0.000      17.940
 input       4        220.000      0.000      0.000     220.000
 LISTING OF PEERS:
  peer   lambda weight
    1      1.000


Results for firm:     2
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable           original     radial      slack   projected
                        value   movement   movement       value
 output      1     168739.000      0.000      0.000  168739.000
 input       1          5.000      0.000      0.000       5.000
 input       2          0.000      0.000      0.000       0.000
 input       3         16.840      0.000      0.000      16.840
 input       4        220.000      0.000      0.000     220.000
 LISTING OF PEERS:
  peer   lambda weight
    2      1.000
```

```
Results for firm:      3
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable            original        radial         slack     projected
                         value      movement      movement         value
 output      1      244862.000         0.000         0.000    244862.000
 input       1           6.000         0.000         0.000         6.000
 input       2          12.000         0.000         0.000        12.000
 input       3          52.900         0.000         0.000        52.900
 input       4         546.000         0.000         0.000       546.000
 LISTING OF PEERS:
  peer    lambda weight
    3       1.000
```

Year: 2019

```
Results from DEAP Version 2.1
Instruction file = A19-ins.txt
Data file         = A19-dta.txt

 Output orientated DEA

 Scale assumption: VRS

 Two-stage DEA method

 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

     1  1.000  1.000  1.000  -
     2  1.000  1.000  1.000  -
     3  1.000  1.000  1.000  -

 mean  1.000  1.000  1.000

Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

 SUMMARY OF OUTPUT SLACKS:

 firm  output:          1
    1               0.000
    2               0.000
    3               0.000
 mean               0.000


 SUMMARY OF INPUT SLACKS:

 firm  input:           1          2          3          4
    1               0.000      0.000      0.000      0.000
    2               0.000      0.000      0.000      0.000
    3               0.000      0.000      0.000      0.000

 mean               0.000      0.000      0.000      0.000
```

SUMMARY OF PEERS:

firm	peers:
1	1
2	2
3	3

SUMMARY OF PEER WEIGHTS:
(in same order as above)

firm	peer weights:
1	1.000
2	1.000
3	1.000

PEER COUNT SUMMARY:
(i.e., no. times each firm is a peer for another)

firm	peer count:
1	0
2	0
3	0

SUMMARY OF OUTPUT TARGETS:

firm	output: 1
1	5272.000
2	88907.000
3	145462.000

SUMMARY OF INPUT TARGETS:

firm	input: 1	2	3	4
1	0.000	0.000	17.940	220.000
2	5.000	0.000	16.840	220.000
3	6.000	12.000	52.900	546.000

FIRM BY FIRM RESULTS:

Results for firm: 1
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)
PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	5272.000	0.000	0.000	5272.000
input	1	0.000	0.000	0.000	0.000
input	2	0.000	0.000	0.000	0.000
input	3	17.940	0.000	0.000	17.940
input	4	220.000	0.000	0.000	220.000

LISTING OF PEERS:

peer	lambda weight
1	1.000

Results for firm: 2
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)
PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	88907.000	0.000	0.000	88907.000
input	1	5.000	0.000	0.000	5.000
input	2	0.000	0.000	0.000	0.000
input	3	16.840	0.000	0.000	16.840
input	4	220.000	0.000	0.000	220.000

LISTING OF PEERS:

peer	lambda weight
2	1.000

```
Results for firm:     3
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable            original        radial         slack     projected
                         value      movement      movement         value
 output     1       145462.000         0.000         0.000    145462.000
 input      1            6.000         0.000         0.000         6.000
 input      2           12.000         0.000         0.000        12.000
 input      3           52.900         0.000         0.000        52.900
 input      4          546.000         0.000         0.000       546.000
 LISTING OF PEERS:
  peer   lambda weight
    3      1.000
```

Year: 2020

```
Results from DEAP Version 2.1

Instruction file = A20-ins.txt
Data file        = A20-dta.txt

 Output orientated DEA

 Scale assumption: VRS

 Two-stage DEA method

 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

    1  1.000  1.000  1.000  -
    2  1.000  1.000  1.000  -
    3  1.000  1.000  1.000  -

 mean  1.000  1.000  1.000

Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

 SUMMARY OF OUTPUT SLACKS:

 firm  output:          1
    1               0.000
    2               0.000
    3               0.000
 mean               0.000


 SUMMARY OF INPUT SLACKS:

 firm  input:          1          2          3          4
    1              0.000      0.000      0.000      0.000
    2              0.000      0.000      0.000      0.000
    3              0.000      0.000      0.000      0.000

 mean              0.000      0.000      0.000      0.000
```

```
SUMMARY OF PEERS:

 firm  peers:
   1      1
   2      2
   3      3

SUMMARY OF PEER WEIGHTS:
  (in same order as above)

 firm  peer weights:
   1   1.000
   2   1.000
   3   1.000

PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
   1       0
   2       0
   3       0

SUMMARY OF OUTPUT TARGETS:

firm  output:          1
   1          11437.000
   2          65071.000
   3         317860.000


SUMMARY OF INPUT TARGETS:

firm  input:         1          2          3          4
   1             0.000      0.000     17.940    220.000
   2             5.000      0.000     16.840    220.000
   3             6.000     12.000     52.900    546.000


FIRM BY FIRM RESULTS:

Results for firm:     1
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable          original      radial       slack    projected
                       value    movement    movement        value
 output      1     11437.000       0.000       0.000    11437.000
 input       1         0.000       0.000       0.000        0.000
 input       2         0.000       0.000       0.000        0.000
 input       3        17.940       0.000       0.000       17.940
 input       4       220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    1      1.000

Results for firm:     2
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable          original      radial       slack    projected
                       value    movement    movement        value
 output      1     65071.000       0.000       0.000    65071.000
 input       1         5.000       0.000       0.000        5.000
 input       2         0.000       0.000       0.000        0.000
 input       3        16.840       0.000       0.000       16.840
 input       4       220.000       0.000       0.000      220.000
 LISTING OF PEERS:
  peer   lambda weight
    2      1.000
```

```
Results for firm:     3
Technical efficiency = 1.000
Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
  variable            original       radial        slack     projected
                         value     movement     movement         value
 output     1      317860.000        0.000        0.000    317860.000
 input      1           6.000        0.000        0.000         6.000
 input      2          12.000        0.000        0.000        12.000
 input      3          52.900        0.000        0.000        52.900
 input      4         546.000        0.000        0.000       546.000
 LISTING OF PEERS:
  peer   lambda weight
    3      1.000
```