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Measuring Efficiency of Container Seaports in Mexico

By

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Abstract
The aim of this study is to determinate whether Mexican seaports operating more efficient are those attracting higher levels of cargo traffic in terms of total throughput. This paper use DEA(Data Enveloped Analysis) which is non-parametric approach commonly used for assessing relatively efficiency on seaports. The model estimates the relatively technical efficiency among principal container ports in Mexico.

The study takes into account three inputs (berth length, storage area and number of Cranes) and two outputs (containers throughput and general cargo throughput) for calculating technical efficiency using DEA output oriented in two variants CCR model and BCC model.

In addition, the study provides an overview of the port system in Mexico, the Mexican port reform of 1993, the process of containerization and hinterland connectivity.

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1. Introduction

1.1 Introduction

Diverse analytical tools or techniques have been used for measuring port efficiency. The multi activity nature of ports and dissimilarities on existing data are a considerable challenge to any practitioner while determining an appropriate set of tools for analyzing port efficiency. Ports are complex entities where diverse activities with different scopes and natures interact. However, the existence of a certain degree of standardization for container terminals has lead to an increased interest in measuring their performance leaving apart integrated analysis of total port productivity.

The role of a seaport can be well described in the UNCTAD (United Nations Conference on Trade and Development) definition: “Seaports are interfaces between several modes of transport, and thus they are centres for combined transport. Furthermore, they are multi-functional markets and industrial areas where goods are not only in transit, but they are also sorted, manufactured and distributed. As a matter of fact, seaports are multi-dimensional systems, which must be integrated within logistic chains to fulfil properly their functions. An efficient seaport requires, besides infrastructure, superstructure and equipment, adequate connections to other transport modes, a motivated management, and sufficiently qualified employees”

The increase concentration in ownership of shipping lines and merges had implied more power for negotiation concessions of facilities within Seaports. As a consequence, competing ports look for increase their productivity and reduce cost for attracting shipping lines. In this context efficiency measurement is a good way for monitoring changes in port productivity.

The finality of this paper is to evaluate technical efficiency between six Mexican container ports by evaluating which ports allocate more efficiently its resources while produce certain amount of outputs (throughput). The relevance of the study is to identify whereas ports attracting more cargo flows are those ports operating under higher levels of efficiency.

There are numerous variables affecting port productivity directly and indirectly, however UNCTAD (1999) mentions two categories of indicators for measuring seaports performance; the macroeconomic indicators, which quantify the aggregate impact of ports on economic activity and the microeconomic performance indicators which mainly evaluate factors´ productivity (Bichou and Khalid, 2004).

The level of efficiency of a port depends on certain elements in its production process, in particular those associated with the rational use of resources (Garcia, 2007). This study will focus on the microeconomic perspective using a nonparametric method of measuring technical efficiency known as Data Envelopment Analysis (DEA); which had become one of the most important and well accepted tools for measuring port efficiency.

1.2 Aim of the Study

Martner and Moreno (2002) affirm that until the past 15 years or so, seaports did not play a significant role in Mexico´s commercial and economic activity. Five decades of economic protectionism and the lack of public policies led Mexican ports to operate inefficiently under inappropriate working practices and limited infrastructure.

However, in 1981 Mexico experienced a change on economic policy moving from a relatively "close" market into a more open "neoliberal" economic model impacting positively trading and consequently improving Mexican Seaports performance. Even though, the real port development was until 1993 with the introduction of a seaport reform that changed the legal framework and permitted seaport´s decentralization and privatization. As a result ports were able to adopt more customer oriented practices.

The progressive introduction of containerization in Mexico made possible multimodal transportation and subsequently pushed forward the development of hinterland networks. As a consequence, Mexican firms were able to participate into global supply chains demanding competitive seaports services and situating Mexican ports in an unprecedented competitive situation.

Incessant changes in international transportation and stricter customer needs place port managers under great pressure for improving ports performance; thus, a comparison based on efficiency analysis is good way for benchmarking Mexican seaports.

The aim of this study is to determinate whether Mexican container ports operating more efficiently are those attracting higher levels of traffic. The study is supported on technical efficiency analysis based on DEA (Data Envelopment Analysis) which is non-parametric approach commonly used for assessing relatively efficiency on seaports. In addition the study provides an overview of the port system in Mexico and its trends.

1.3 Thesis Structure

Productivity and efficiency are terms which may cause some degree of confusion, therefore a complete explanation of both terms will be presented in Chapter 1, followed by a literature review on port efficiency. The finality of Chapter 2 is to explain the Mexican port reform of 1993. In order to do so, the chapter starts with a short review of port privatization and port governance and ends with the explanation of the process for port liberalization and decentralization in Mexico.

Chapter 3 introduce the concept of containerization, following by describing the incursion of containers in Mexico and how containerization was a major trend for standardizing cargo handling methods permitting the multimodality of transportation (rail, road) and consequently the emergence of global supply chains. The chapter ends whit an overview of the principal container ports in Mexico.

Chapter 4 provides a short overview of the hinterland network in Mexico providing details of the railroad system and roads. In addition, this section describes the reasons of why geographic location can be considered as determinant for efficiency.

Chapter 5 clarifies the methodology used, this section explain DEA (Data Envelopment Analysis) technique for measuring port efficiency. The chapter includes an explanation of the selection of factors used as Inputs or outputs.

Chapter 6 exhibits the results obtained by using both methodologies DEA CCR and DEA BBC and finally the study ends with the conclusions reached.

1.4 Literature on Port Efficiency

In the past decades, seaport efficiency and seaport productivity has gained special attention from researchers. Few reasons can be attributed to this particularity, for instance those related to the constant improvement of cargo handling practices promoted by globalization, containerization and evolution in logistics and production systems coupled with organizational changes and privatization.

There are extensive literature available for comparing seaports performance; however discussions remains about whether these models are able to describe the complex ports reality accurately or not. According to the OECD (2008), with containerization, ports in the same region become closer substitutes, and hence are more exposed to competition. The basic principle for comparisons suggest that these must be perform between similar entities/organizations; this explains why many author´s focus on the analysis of container terminals since exist high degree of standardization.

A particularity of Mexican port system is that most of the ports operate under apparent similar circumstances in terms of managerial structure, port governance, labour and legal framework making possible to do a fair inter-port productivity comparison. However, some dissimilarities or relatives competitive advantages or disadvantages may exist between competing ports. For example: Geographical location, hinterland connectivity and accessibility.

Various researchers have carried out multiple mathematical models to investigate the challenges of port productivity. For instance Chang (1978) employs multiple regression analysis to estimate a Cobb–Douglas production function to extrapolate port productivity, Jara-Dıaz (2002) developed a multi-output cost function to gain insights on the efficient use of resources, Sachish (1986) found that the volume of activity and capital investment are of major influence on total productivity.

Tongzon (1995) conducts a short-term analysis on measuring container terminal efficiency, others have studied the relationship between output and efficiency, including Caves and Christensen (1988) and De Neufville and Tsunokawa (1981).

Estache et al. (2002, 2004) conclude that efficiency of ports increases with the increasing competition and decentralization of port authorities. Several studies propose that benchmarking is the best way of regulating ports, Tongzon (2001) and Estache et al. (2002). A different methodology widely used is TFP or Total Factor Production; which consist on the elaboration of an index that will reflect the overall contribution of all relevant input and all outputs. Some examples are: Martinez-Budri (1998), Martin (2002), Diaz (2003), Estache et al. (2004), Guerrero and Rivera (2009).

Wang et al (2002) and Roll and Golany (1991) coincide that Data Envelopment Analysis is an effective method for evaluating port efficiency. They suggest that DEA is one of the most important and useful approaches for its simplicity and wide range of applications. DEA was first applied in 1978 (Charnes et al) and has been widely used for determining relative seaports technical efficiency.

DEA consists in establishing different weights on multiple factors for calculating the productivity function. Martinez-Budria et al (1999) applied DEA for evaluating the relation between degree of complexity and efficiency in twenty six Spanish ports. Using DEA, Tongzon (2001) made an international comparison of efficiency in four Australian ports and 12 other ports around the world.

Bonilla et al (2002) conducted DEA for analyzing the relation between cargo handling equipment and commodities traffic in twenty three Spanish ports. Barros and Athanassiou (2004) estimated the relatively port efficiency of some ports in Portugal and Grecee.

More recently Wang and Cullinane (2006), use DEA for measuring port efficiency of one hundred and four container terminals around Europe. They found that larger terminals which enjoy the benefits of economies of scale are also the most efficient. Herrera and Pang (2008) studied the efficiency on eighty six container terminals around the world using Free Disposable Hull (FDH) and DEA. They conclude that efficient container terminals allocate their resources 20 to 40 percent more efficiently.

However DEA results may vary according to the inputs and outputs selection, since the method aloud wide range of possible variables. Even thought do not exist a clear standardization of the procedure Golany and Roll (1989) proposed an application procedure in which included some recommendations.

1.5 Efficiency Vs. Productivity

Many times the change in productivity is due to changes in efficiency, which can quickly lead to confusing the two terms. Efficiency is a word that we use to describe the amount of effort or energy that it takes to accomplish a certain task or operation. When a process has many operations/activities happening all at the same time, each operation should be as efficient as possible.

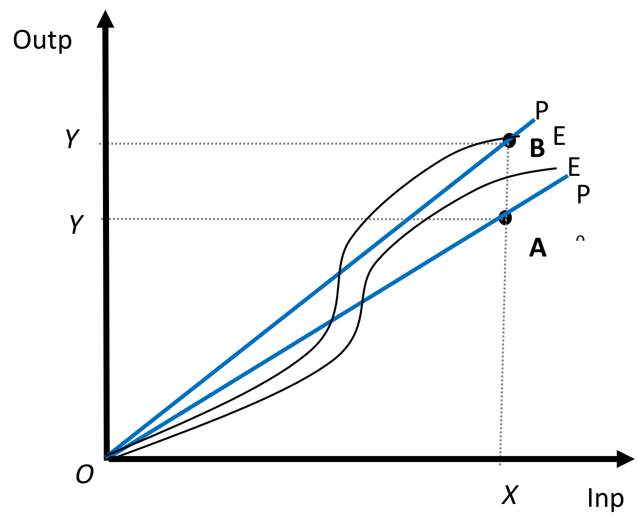
Productivity is a measure of how much work is done in a certain amount of time. Many authors have measured productivity as the amount of output per unit of input. Therefore, if each activity works efficiently, they will contribute to improve the productivity overall in the system.
In general, researchers have considered that productivity of seaports can be estimated by the amount output produced divided by inputs utilized. Where output is throughput (Tons, TEU, etc) and inputs are the resources available (Land, Labour, Energy).

The following graph would help to clarify the difference between Productivity and Efficiency.

Productivity line (P): is derivate by the function y=outputs / inputs at a particular scale of production.

Efficiency line (E): Is the technical efficiency of production and is express as a function of maximum productivity possible under certain technological conditions. Graphically is denoted by the production frontier curve.

Figure 1: **Illustration of efficiency and productivity**



Source: Author based on Wang et al (2002).

According to Farrell (1957), technical efficiency will indicate if all resources and technology available are being properly used (Guerrero and Rivera, 2009).

Point **A** is a dot in a productivity function of a particular port operating under certain technical efficiency, therefore under this particular circumstances, port will be able to produce (*Y*) outputs based on (*X*) resources or inputs. Point **A** is located below to the production frontier (E_0), therefore is being inefficient.
The productivity level of point A is represented by the area behind the productivity function, $P_{0.}$

The production frontier curve can be described as the natural level of maximum efficiency observed according to the degree of technology and capital available.

However, technical innovations will come up simplifying process and simultaneously reducing time and cost and therefore making activities more efficient. Graphically, this would be represented by a Shift in the production frontier curve from (E_0) to (E_1).

As a consequence and in the assumption that a particular port designates same amount of resources/inputs (but more efficiently allocated), a shift from point **A** to point **B** will occur. (P1) is the new port productivity function, (E1) shows the new production frontier and (Y_1) is the new output produced based on (X) inputs.

The productivity gained (P_g) due to a change in technological efficiency can be express by the ratio of the productivity of point A to that of point B by:

$$PG = \frac{(XA)/(0X)}{(XB)/(OX)}$$

In other words, a change in productivity function from (P_0) to (P_1) was caused due to a change in port technical efficiency from point **A** to **B**. Even though both points are located under different production frontier curve, point **A** underperforms in terms of technical efficiency while point **B** is operating efficiently.

2. Port Privatization in Mexico

2.1 Introduction

Many authors will agree that port privatization has a direct impact on ports performance; there are some studies which demonstrate the relationship between ownership structures and port efficiency with varied results. However ports privatization had gain acceptance by many countries in the last decades.

There exists a generalized and well accepted idea that seaports form a vital link in the overall trading chain and, consequently, an efficient seaport system is considered by nations as a vital factor for achieving international competitive advantages (Tongzon,J. 2005). According to the World Bank (2001), Since the latest 1980´s many national and state level government have adopted institutional reforms in the port sector such as privatization and corporatization with the aim of decentralizing terminals operations functions from the governments hands (Cheon,SangHyun, 2010).

Mexico didn´t escape to this phenomenon, in 1993 the overall seaports system experienced a major reform with the objective of decentralizing ports activities from government and to attract private investment and hence improve the overall productivity of the seaport structure.

This chapter presents a brief review of the concept of privatization and port governance options followed by the main characteristics of the Mexican port reform of 1993 which can be consider as a major trend for seaports modernization in Mexico. Also presents, a short recap of the concept of API`s (Administración Portuaria Integral) and their role in current port system.

The chapter mentions the 23 main commercial ports that have joined the API scheme and explain the trading patterns in Mexico showing the main origins and destinations of goods transported by sea.

2.2 Privatization

Privatisation can be defined as the transfer of ownership of assets from the public to the private sector or the application of private capital to found investment in port facilities, equipment and systems (UNCTAD, 1998).

Privatisation of seaports has played a crucial role; the intervention of private entities has revolutionised the way ports are operated, administrated and financed. The generalized idea that privatisation is a reliable way to increase efficiency, suggests that the less the public sector is involved the more flexible the administration of a port can be and thus, the more efficient a port can be.

The objective of privatization is to reduce operating costs and raise profit maintaining high standards to be competitive. Seaport development and operations are high capital-intensive activities, and over the last three decades many countries have implemented policies aimed at reforming their port industries for improving efficiency and financing new projects.

The strengthening role of private operators and investors in seaports infrastructure has achieved a significant level of acceptance worldwide; from an economic perspective, Adam Smith (1776), already suggested that private ownerships tends to improve performance as private investors pursue their own business interest. He showed how competition and the drive for profit would lead individuals to supply the type of service that others desire. Moreover, by competing against one another, only firms that produce what was wanted and at the lowest price possible would survive.

Various alternatives exist for introducing private participation which consists of different types or degrees of freedom for the private sector. Privatisation, corporatization, commercialization and deregulation are some concepts used for promoting a greater private role in economic activities; concepts that may include various modes or forms of privatisations such as licenses and concessions, leasehold contracts, and different types of arrangements. Some schemes of privatisation (Rus, 2000) are:

- Full Privatisation: Consist in selling the seaport as a whole.
- Build-Operate-Own (BOO): Consists of transferring parts of seaports to private operators for development.
- Build/rehabilitate-operate-transfer (BOT): Introducing private participation in the port to build or renovate facilities required where facilities built with private investment are transferred to the public sector, in other words the public sector do not lose control over the seaport.
- Joint ventures: The main purpose is to create collaboration between Private and Public sector for working together in particular projects.
- Leasing: Port authorities retain assets from private operators for a fixed period, the purposes to gain income from contract fees.
- Licensing: Port authorities allow private operators to use their own equipment to provide specific services; usually required equipment is not very specialized.
- Management contracts: Introducing private participation in simple form by outsourcing the port management. This form may suggest that private firms can provide a more commercial approach while port authorities remain as owners of infrastructure and facilities.

National legislations and local authorities play a key role in the process of making guidelines for seaports privatisation. Some objectives for the privatizing sea of ports are: new business development, sharing risk between the public and the private investors, introduction of technology, know-how, etc.

2.3 Port Governance

Traditionally port authorities played the role of facilitator, focusing on the provision of superstructure and infrastructure for ship operations, loading/unloading, temporary storage and intra-port operations. Moreover, the ownership and management of ports, namely governance, is considered one of the characterization factors that influence port performance and efficiency (Tongzon,J , 2005).

According to the OECD (1999), corporate governance is defined as “the system by which business corporations are directed and controlled.” Adapted to the specific case of ports, very close attention should also be paid to the “distribution of rights and responsibilities” between the various stakeholders. Moreover, a clear structure for decision making, objectives setting and performance evaluation should in theory derive from the split in functions and responsibilities, allowing the port to operate in a satisfactory way. However, in practice the case is much more complex with various stakeholders having often divergent interests.

Four port administration models are distinguished under the World Bank Port Reform Tool Kit:

- Service port model: In this governance model the public sector owns and operates the land and all assets (infrastructure, superstructure, cranes…) of the port. All regulatory functions are solely of public responsibilities and so are all port functions from day-to-day, cargo-handling to planning operations. In most cases the port is directly under the control of a Ministry, thus the top-management is often appointed by politicians and has a civil servant status. Whereas such concentration of power may be beneficial in the sense that only one authority has the entire responsibility, which leads to more consistent and cohesive long-term strategy as well as smoother operations this governance nevertheless suffers from inefficient administration, lack of innovation and market-oriented services. Moreover the use of public funding for the port tends to be never very efficient: in most cases public ports suffer from investments that are either insufficient (under-investment) or wasteful (over-investment) due to the lack of market orientation.

- Tool port model: Although in this governance model the Public Authority owns and develops the port (both infra and superstructure), a number of privately owned companies are involved typically in cargo-handling operations alongside the Port Authority. While this model introduces private public partnership on a limited level, the issue that often arises is the responsibility split for the cargo-handling operations: small private companies, stevedoring companies and port administrators often have relatively redundant responsibilities. This model suffers – as the service port model – the risk of under-investment due to the public ownership which can be reluctant to invest the necessary sums for political or other reasons.

- Landlord port model: The landlord port governance model is perhaps the best example of joint public and private partnership: on the one hand the Port Authority remains the owner of the port however it leases the infrastructure to private companies often for long periods. These companies manage the superstructure as they deem fit, buying and managing cranes and other cargo-handling equipment. The Port Authority however keeps responsibilities in long-term development of the land, maintenance of the roads, berths, rails, wharves and all other type of infrastructure. This task and responsibility repartition favours a more market-oriented and more efficient operation management because the party that owns and operates the shore equipment is a profit-driven private company, thus being faster to respond to market evolutions. There are multiple other arguments in favour of such a partnership, however they will be listed in a separate part.

- Private service port: In this last model defined by the World Bank Port Reform Tool Kit, the public authorities have abandoned all interest in the port activities: the private sector (one or more operators) owns the land and exercise all regulatory and operational functions. This model is widely used in the United Kingdom; This models allows vast flexibility in terms of investment and high adaptability of the pricing structure as well as the development planning since it is focused on the market. The draw-back of being so market driven can be the lack of long-term vision and strategy. From a more general prospective, this model may encourage monopolistic behaviour which will detriment all related stakeholders and cause a significant welfare loss to society.

Although, in theory the above mentioned models are well defined, it seems that port governance in practice cannot be either so rigid or so well delimited. In practice most of the country´s ports systems are a mix of both private and public sector involvement; mainly because of the complex nature of ports and the socio-economic structure of the country.

2.4 Port Reform in Mexico

Before 1980´s, Mexico´s economy was significantly “closed”, largely controlled by state and mixed capital within a highly regulated private sector. Government strictly controlled foreign investment and barred private investors from many activities including transportation (railroad, road, airports and seaports). Moreover, prices of goods and services where strictly regulated by the government (Encyclopedia Britannica, 2010).

In 1981 the economic policy adopted a neoliberal economic approach by deregulating many industries and consequently the dissolution of state enterprises. The finality of the new economic model was to attract direct foreign investment for promoting internal competition and to incentivize international trading by removing most of the imports and exports restrictions.

However, real modernization of Mexican ports started only in the middle 1990´s when a new governmental initiative established the new legal framework for decentralizing the transportation industry. Previously, seaports where centrally managed and operated by a government stated own monopoly known as PUMEX (Puertos Mexicanos). This agency was responsible for administrating and operating all seaports.

Between 1990 and 1994, the Mexican port system received on average sixty five million pesos a year to subsidize seaports operations evidencing the operative inefficiency of seaports prior to the adoption of the port reform (World Bank, 2003).

The adoption of new public management principles and the ensuing devolution of port management has resulted in a better commercial approach and increased customer awareness to the management of port operations (Brooks and Cullinane, 2007).

According to the World Bank (2003), the Mexican Seaports reform rested in three key instruments: decentralization, privatization, and the introduction of competition in the port system.

- Decentralization implied that each port needed to have an autonomous, self-financing port administration which would benefit from increased independence and better management due to the reduction in bureaucratic procedures. Moreover, decentralization implies that the local port authorities and the government adopted just a supervisory role for building a clear decision-making structure for improving seaports performance.

- Privatization required that port industry had to be opened to the participation of private investors. However, according to Mexican Law, foreign investment is restricted up to 49% of the total investment. Nevertheless opening the market to foreign capital has had an important impact as it allowed the development, construction and entering in operations of several new specialized terminals.

- Introduction of competition was related to the necessity of fomenting intra-port competition (within a specific port) and inter-port competition (between two or several different ports) in order to provide additional incentives to port operators and terminals to increase their productivity and reduce monopolistic practices. Doing so required however four main steps: first the liberalization of tariffs, secondly the elimination of subsidies, thirdly the reduction of entry barriers and finally the liberalization of the labour market.

The objective of the seaport reform was to develop modern port facilities but at the same time to improve the living standards of the population and support the expansion of industrial activity with the aim of boosting the economic growth of the country.

The key element of the Mexican port reform was the creation of institutions with the legal status of a commercial company named API (Administración Portuaria Integral). APIs are the companies in charge of managing seaports; somehow they act as landlords since the port law precludes port operators and requires them to contract services with third parties. The board of APIs must include representatives from the federal, states and municipal level, and in some cases from private sector(World Bank, 2003).

APIs are authorized to sign contracts for the partial cession of rights to third parties, allowing private firms to undertake the construction, expansion and operation of terminals as well as the provision of port services (Martner. C, 2002).

The federal government through the SCT (Secretaría de Comunicaciones y Transportes), retains the role of port authority and is the agency that grants all concessions, licenses and authorizations. SCT also acts as a regulator by determining maximum tariffs (World Bank 2003).

Safety and security are the responsibilities of the navigation authority (Capitanía de Puertos); which is independent of the SCT. However, another important player is the navy (Secretaría de Marina Armada de Mexico) which main role consist in preserving national security and prevent the traffic of illegal merchandise (Drugs).

APIs Increased capital investment in ports producing substantial improvements in infrastructure and equipment, as well as the implementation of new administrative and operative practices that have been more and more customers oriented. However, port restructuring and privatization has lead to an increased concentration of cargo and investment in few “winner ports” (Ojeda, 2000). Thus not all ports have benefited equally from the new scheme, since the ¨winner ports¨ that have a more attractive location, possibility to accommodate newer larger vessels, space for further expansion, better hinterland connectivity have gathered a larger market share of the cargo.

In general, benefits of the port reform of 1993 are evident. There are few studies available under this subject; Carlos Martner (2002) estimates that the annual average cargo growth rate in Mexican ports between 1990 to1995 was two percent while from 1995 to 2000 reach six percent. Even more, Estache et al (2001) conducted an analysis based on stochastic production frontier for studding efficiency gain in Mexican ports caused by the port reform. They came up with tree main conclusions:

1) Mexico´s experience suggest that reforms promoting management autonomy can generate large short term improvements. Mexican ports achieved 2.8% to 3.3% average annual efficiency gains since the reform.

2) The studies of port efficiency are relevant for any authority in order to pass the benefit to the final port users.

3) The analytical results can help to promote yardstick competition in the sector. An also to warranty that any gain in efficiency can be reinforced over the long run through strategic planning.

As a matter of fact, the Mexican seaport system better fits on the Landlord model which has a combination of private and public participation, however some restrictions in percentage of total private participation remain.

2.5 Mexican Port System after the Port Reform

Historically, seaports in Mexico had present high degree of cargo handling specialization which was mainly linked to the economical activity of their limited region of influence. Prior to the commercial aperture and the port reform of 1993 no inter-port competition existed and very limited or null intra-port competition. Progressively this situation had been changed.

At present, Mexican port system consists of 114 ports distributed along the 11,122 km of coastline, of which only 26 handle ocean going cargoes. There are 23 ports under the scheme of API (Administración Portuaria Integral) and 1 ACI (Administración Costera Integral) which is a similar scheme but regionally controlled. These 24 ports are dedicated mainly to commercial activities and passengers.

Table 1: **Mexican Ports under API and ACI Schemes**

Port	Administrative scheme	Owned	Port Authority
Acapulco	API	Private	SCT
Altamira	API	Federal Government	SCT
Baja California Sur	API	State Government	SCT
Cabo San Lucas	API	Federal Government	Fonatur
Campeche	API	State Government	SCT
Coatzacoalcoz	API	Federal Government	SCT
Cozumel	ACI	Municipality and State	Independent
Dos Bocas	API	Federal Government	SCT
Ensenada	API	Federal Government	SCT
Guaymas	API	Federal Government	SCT
Huatulco	API	Federal Government	Fonatur
Lázaro Cárdenas	API	Federal Government	SCT
Manzanillo	API	Federal Government	SCT
Mazatlan	API	Federal Government	SCT
Progresp	API	Federal Government	SCT
Puerto Chiapas	API	Federal Government	SCT
Puerto Vallarta	API	Federal Government	SCT
Quintana Roo	API	State Government	SCT
Salina Cruz	API	Federal Government	SCT
Tabasco	API	State Government	SCT
Tampico	API	Federal Government	SCT
Topolobampo	API	Federal Government	SCT
Tuxpan	API	Federal Government	SCT
Veracruz	API	Federal Government	SCT

Source: Author, Data from SCT.

According to the Mexican Transportation Institute (IMT), in 2008 all commercial ports where able to handle 194.8 millions of tons of cargo, from which 42.7% correspond to exportations and 57.3% to Importations. The total volume is compound by four main types of cargo: Crude oil and derivates which represent almost the half of the volume with 53%, mineral bulk contributes with the 20% of the total volume, general cargo with the 16% and finally 5% belongs to agriculture and grains. However, taking apart crude oil cargo, the total amount of cargo is reduced to 85.3 million tons.

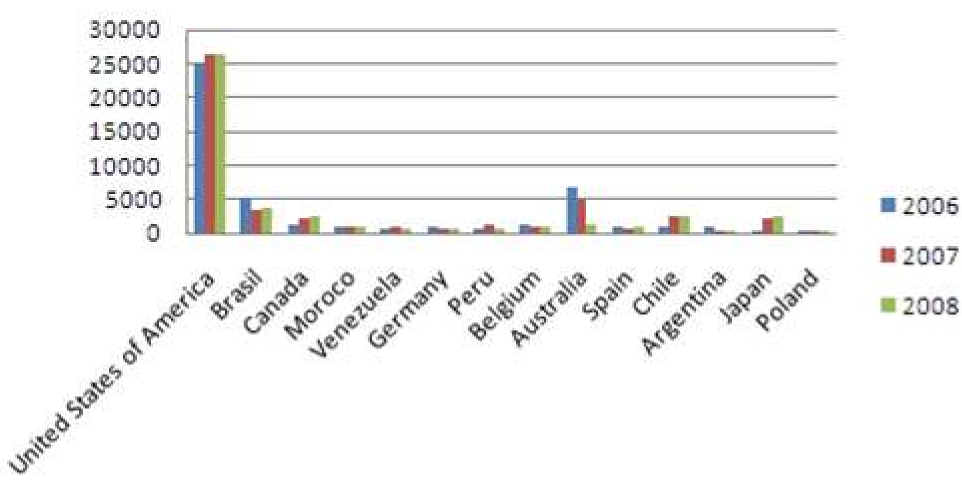
In the face of the fact that Mexico is an important crude oil producer and therefore significant percentage of total maritime transported cargo is crude oil and oil derivates, the analysis presented here would not include oil cargo since the operation, commercialization, and transportation is fully controlled by a state owned monopoly (PEMEX) and its subsidiaries.

Scholars agree with the existence of a positive relation between countries GDP growth and trade and consequently trade and transportation is strongly linked. A peculiarity of international trade is that neighbouring countries tend to trade more among themselves; for instance Mexico´s market is strongly tied to United States economy.

Analysing the origin/destination pars of trade of good by sea (Figure 2 and 3) is obvious the strong link between both economies. Mexico presents a positive balance between exportations and importations. However from 2007 to 2008, the importations from United States remain unchanged while the exportations from Mexico to United States were significantly reduced as a cause of the global economic crisis.

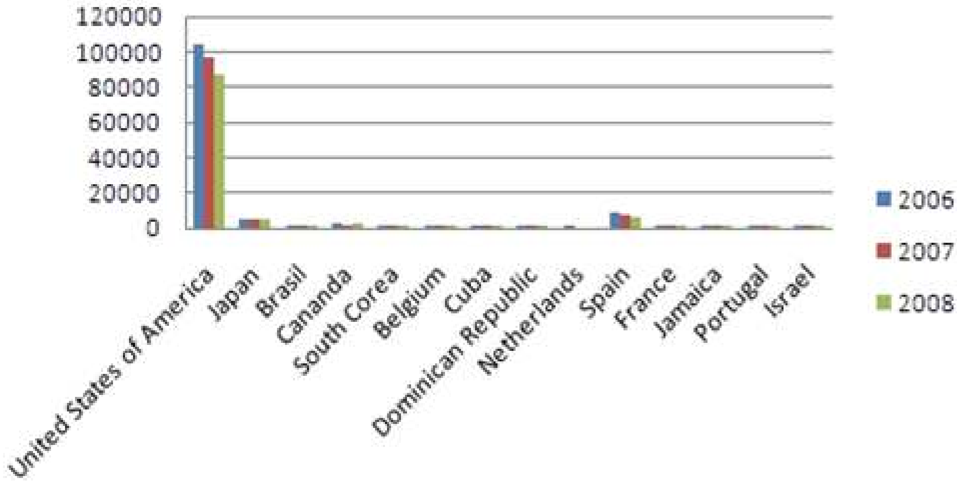
Trading between Mexico and Asia had gain importance incentivised by the good development of Asiatic economies and the development of a commercial corridor which permits the movement goods from some Mexican seaports to United States. The more evident example are ports of Manzanillo and Lázaro Cárdenas which are communicated by rail to the East Coast of United States.

Figure 2: **Origins of Importations by Sea (tons).**



Source: Author, data from Mexican Transportation Institute (IMT)

Figure 3: **Destination of Exportations by Sea (tons).**



Source: Author, data from Mexican Transportation Institute (IMT)

Figure 4, shows a map indicating trades of goods by sea between Mexico and other regions. The map illustrates the regionalization of the trading showing that 78.8% of the Mexican exportations and 62.7% of the importations are from and to United States or Canada; confirming the idea that neighbouring countries tend to trade more. However the trading is strongly motivated by the NAFTA (North America Free Trade Agreement) zone.

Figure 4: **Trades of Goods by Sea between Mexico and other Regions**

Source: Manual Estadístico del sector transporte. SCT/IMT(2009)

3. The Process of Containerization in Mexico

3.1 Introduction.

Containerization was a major technological innovation that revolutionized the nature of maritime-based freight transport of manufacturing goods. It caused a substantial degree of standardization of port services. In addition, with containerization ports in the same region become closes substitutes, and hence more exposed to competition from other ports and other routes (OECD / ITF, 2008).

This chapter starts with a short recap of the history of containerization and continues with some statistics about containers traffic flows in Mexico. Also, presents a short description of the concept of hub and spoke, an explanation of how carriers had reach economies of scale and the development of hub ports in Mexico.

The chapter ends with a brief overlook of the principal container ports in Mexico: Altamira, Ensenada, Manzanillo, Lázaro Cárdenas, Progreso, Veracruz. Same port which had been chose for evaluating their technical efficiency using DEA methodology.

3.2 Containerization

The initiator of the container was Mr. Malcolm McLean who in 1956 shipped fifty eight containers onboard of the M/T Ideal-X from Newark, New Jersey to Houston, Texas where fifty eight trucks were waiting for taking the containers to their final destination (Levinson, 2006).This moment had been consider by many as the origin of a revolution in the shipping industry.

According to Levinson (2006), the container made shipping cheap, and by doing so, changed the shape of the world economy. The idea of the containerization consisted in consolidating general cargo into a unitized form or container that permitted the creation of standardized cargo handling process and thus, the launched of an international intermodal transport system.

A container can be defined as a steel box of standardized dimensions (8x8x20 ft) commonly denoted as 1 TEU (Twenty feet equivalent Unit), although containers of double size or 40 ft are more frequently used, the existence of diverse types and sizes of containers for handling more specialized cargo are becoming well accepted by shippers and carriers.

Perhaps, containers where so successful because in principle is a simple idea that bring enormous economic improvements, the more evident improvements are those related with the reduction in time (loading / unloading) and the lessening of hard-labour operations by the introduction of high-tech cargo handling equipment.

Implementation of containerization requires significant amount of capital for the development of specialized terminals, building infrastructure, acquisition of cargo handling equipment and development of hinterland connectivity which is a vital element for integrating supply chains properly.

Some proved advantages of using containers are: The significant reduction on time for loading and unloading, the increasing carrying capacity (ships size), the reduction of cargo damage and pilferage and finally and more important the possibility of multimodal transportation which make possible door to door services. On the other hand, some disadvantages are the significant amount of capital required for the acquisition of specialized equipment and cargo means, another disadvantage is that containers are not always suitable for all types of cargo and finally containers are restricted in size and weight.

Today container´s carriers operate under the principle of "liner" shipping which consists in a fleet of ships under common ownership or management providing fixed services at regular intervals between named ports and offering transport to any kind of goods (Martin Stopford, 1997).

According to Martin Stopford (1997), the process of containerization of the liner trades took about 20 years. However, today all of the major liner routes and most of the minor ones had been containerized. For giving an example; Alan Branch affirm that in 2004 there where over 140 trading nations in the container business embracing 360 ports and generating over 100,000 possible routes.

Authors agree with the generalized idea that in container terminals exist some degree of standardization, however still considerable diversity. Never less the apparent similarity among container terminals had lead to an increase interest in measuring their performance leaving apart the analysis of total port productivity.

3.3 Containerization in Mexico

In Mexico, the process of containerization started in 1980´s, more significantly after 1986 when Mexico formally became a member of the GATT (General Agreement on Tariffs and Trade). The signature as a GATT member bring important structural changes including the reduction on trade regulations and the exclusion of trade permits for a more accessible model of tariffs.

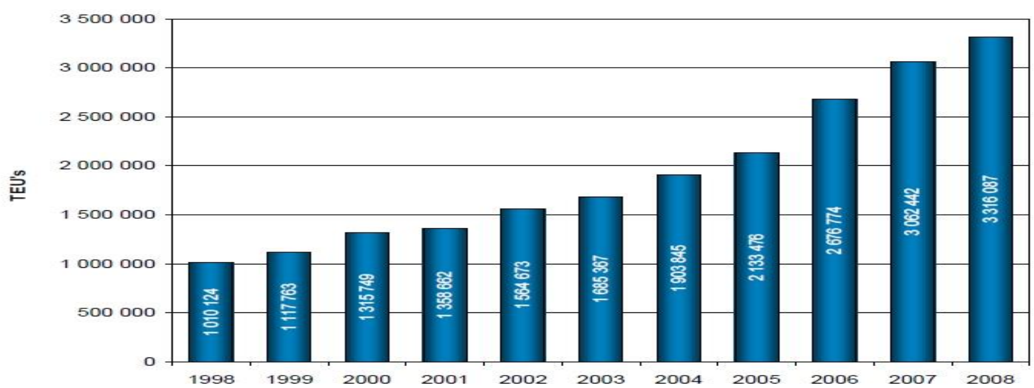
The utilization of containers in Mexico had gain importance in recent years; According to the Mexican Transportation Institute (IMT) in 1993 just 40% of the general cargo was containerized, however in 1999 the situation improved to 53% and by 2007 the percentage of containerized cargo reached 71%. Furthermore, containers total throughput at Mexican ports had experienced a steady growth of 14% during the past 14 years (Figure 2). However, the country stills far from reaching similar container flows of other developing economies. According to the UNCTAD, Mexico is situated on the 21st position of the developing economies, in terms of total container throughput.

As stated by Ojeda (2000), port restructuring of 1993 produce high degree of concentration of cargo. In the case of containers the distinctiveness of concentration is evident. In 2007, the Gulf of Mexico and the Caribbean conjoin the traffic of containers in three ports Veracruz and Altamira and Progreso. The first handled 59.2 % of the containers and the second 33% and the third 5.8%. These three ports concentrate 98%

of the total container flows at the Atlantic Coast. The Pacific Coast follows same pattern, Manzanillo, Lázaro Cárdenas and Ensenada concentrated 98.3% of the containerized cargo in 2007 (See table 1).

The study will focus on measuring efficiency on previous six mention container ports covering 98% of the container traffic in Mexico. All previous mentioned ports have at list one dedicated container terminal.

Figure 5: **Annual Containerized Cargo (1998-2008)**



Souurce: SCT, annual statistical report 2009

Table 2: **Annual Containerized Cargo by Coast (2000-2007)**

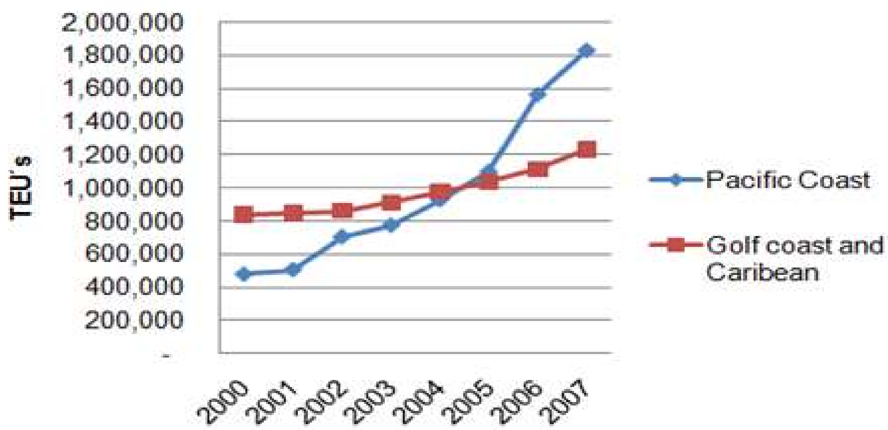
	2000	2001	2002	2003	2004	2005	2006	2007
Pacific Coast	477,658	505,668	704,800	773,861	928,204	1,098,447	1,564,173	1,830,387
Ensenada	26,822	26,016	53,142	46,332	39,202	75,101	123,711	120,324
Mazatlán	16,813	18,315	12,900	16,394	15,954	17,559	30,111	29,363
Manzanillo	426,717	458,472	638,507	708,417	829,603	872,386	1,249,630	1,409,614
Lázaro Cárdenas	752	-	134	1,646	43,445	132,479	160,696	270,240
Salina Cruz	5,332	2,865	84	1,070	-	922	-	734
others	1,222	-	33	2	-	-	25	112
Golf coast and Caribbean	835,841	847,430	858,228	910,580	974,356	1,034,766	1,112,518	1,232,033
Altamira	182,545	206,864	225,937	256,417	297,017	324,601	342,656	407,657
Tampico	49,472	29,531	18,848	14,347	9,862	9,001	10,243	11,040
Veracruz	540,014	543,327	548,422	571,867	591,736	620,858	674,872	729,717
Progreso	56,581	60,117	57,787	60,312	68,082	71,769	75,692	75,584
Puerto Morelos	7,125	7,250	6,958	7,515	7,508	8,245	8,887	7,942
others	104	341	276	122	151	292	168	93
TOTAL	1,313,499	1,353,098	1,563,028	1,684,441	1,902,560	2,133,213	2,676,691	3,062,420

Source: Author, Data from SCT

Another particularity in Mexico is the presence of unbalances between container traffic flows at the Atlantic and Caribbean Coast versus the Pacific Coast. What is evident is that the ports located at the Pacific Coast had presented greater growth rates caused by the economic downturn of western economies and the emergence of strong Asiatic economies.

Figure 6, illustrates how seaports located at the pacific coast had success in attracting grater traffic of containers. Previous tendency is significantly more notorious since 2004; year in which Port of Lázaro Cárdenas opened a new dedicated container terminal positioning the port as an important hub for containers.

Figure 6: **Containers Handled in Mexico by Coast**



Source: Author, Data from SCT.

3.4 Development of Hub ports in Mexico

Over the past years, the main liner routes had experiment a continuous increase in the size of containerships. This can be partially attributed to the more flexible forms of cooperation between the main carriers like conferences and more recently the emergence of global alliances. On the other hand this cooperation has created an unusual concentration of the liner industry forming oligopolies.

There have been many discussions whether the main carriers can manipulate or control prices and consequently the use of oligopolistic practices that may have a negative impact on the general welfare. Regardless this concentration, statistics from previous years had proved no negative impact. In fact numbers show a clear reduction in the cost of transportation of goods by sea.

Global alliances had prove been really successful for achieving economies of scale. Main carriers collaborate together for sharing ship´s space for cargo and defining shared routes with fixed itineraries. In addition, technological innovations had made possible to build bigger and more efficient ships.

H. Haralambides (2010) defines economies of scale as the situation whereby unit cost (for pricing and competitiveness) are reduced as a ship size increase. This reduction is more pronounced particularly in the case of shipbuilding cost, manning cost and fuel cost. He also suggests that economies of scale have led to cargo consolidation, storage and distribution; thus emergence of regional hubs.

The significantly high capital needed for operating this mega container ships, obliges them to limits their ports call to a minimum of “hub” port or “load centers” where huge amount of containers are further forwarded (feeder) with smaller vessels to regional and local ports. In this context, Jan Hoffman (2000) defines Hub ports as seaports that concentrate domestic and foreign cargo with different points of origin and/or destination for is subsequent redistribution. Although some seaports do specialize in transhipment and usually those ports are located on the way of main liner routes; This ports are commonly known as a wayports.

The increasing concentration of ownership of shipping lines and merges has meant more power of negotiation to the carriers for getting concessions and facilities from ports. Consequently, competing ports look for higher productivity and less cost in order to attract shipping lines. As such, modern container ports need to exhibit management competency in the pursuit of a suitable strategy and in the allocation of scarce resources (Wang et al, 2002).

Wang et al (2002) suggest that ports performance measures had become the normal way to handle internal and external pressures. Performance indicators are important to the decision making process in order to achieved desired goals. Productivity and efficiency are the most important concepts in measuring performance.

Recently, ports of developing countries including Mexican ports look for attracting cargo by improving their performance, reducing coast and evolving into hub ports for transhipment. Nevertheless not all ports can evolve easily into a hub port.

H. Haralambides (2010) mentions some success factors need for the consolidation of regional ports as a hub ports:

- Strategic location and connectivity to transport networks
- Minimization of overall, generalized, transport cost
- Regional competition with other hubs
- Port dues and productivity
- Sufficient land and nautical infrastructure and space for future development
- Generous government incentives for successful PPPs and creation of a maritime/industrial cluster
- Information technology
- Modern cargo-handling equipment
- Highly skilled, educated and multilingual labor force.
- Excellent business culture and institutional framework
- Political stability and sound economic policies

Ports incorporate set of mixed terminals, each with different clients and different degree of specialization for handling diverse types of cargoes and usually managed by different firms with diverse policy objectives and different strategies. Therefore, traffic growth in different terminals in the same port is unequal. However bigger ports tend to concentrate cargo and become regional hubs.

According to Guerrero and Rivera (2009), In Mexico the ports of Veracruz, Altamira, Lázaro Cárdenas and Manzanillo can be consider as a hub ports, since they concentrate and distribute vast volumes of ocean-going cargo. In 2007 this ports handled 64.8% of the general cargo and 92% of containerized cargo. The existence of secondary but not less important seaports for the overall Mexican port system are Ensenada, Tampico, Coatzacoalcos, Mazatlán and Progreso which handled less volumes but still have substantial market share.

3.5 Container Seaports in Mexico

For the purpose of the study; principal container ports in Mexico will be consider. However, Seaports lacking of specialized container terminal will be excluded (Tampico, Mazatlan) since DEA methodology should be applied to compare efficiency between ports with similar characteristics.

Figure 7 show the location of the seaports to be consider on the evaluation of technical efficiency in Mexico, however ports in red (Altamira, Lázaro Cárdenas, Manzanillo and Veracruz) are hub ports in Mexico while ports in blue (Progreso and Ensenada) are secondary ports but not less important for the aim of the study. Together these ports concentrate 98% of the total containers traffic in Mexico.

Figure 7: **Selected Ports for DEA analysis**

Source: Author.

3.5.1 Altamira

The port of Altamira was created in 1985 as a part of a federal plan for developing industrial ports in Mexico. Prior to de creation of the API in 1994, Altamira was limited to a four general cargo terminals with 750 meter of Berth length and four terminals specialized in liquid chemicals with a total Berth length of 615 m.

However after the creation of the API, 2,834 hectares were additionally included for the development of industrial areas. The port of Altamira had presented enormous dynamism; In year 2000 the port handled 5.7 million of tons, six years latter´s in 2006 the port reach 9.3 million which represents 61% of increment.

Today the port is integrated by three municipalities, Tampico, Altamira and Madero. In the first municipality all commercial activities are concentrated, in the second the oil industry play an important role leaving to the third municipality Altamira all the industrial activity. Today the total area of the port project has 9,595 hectares from which the API of Altamira administrates 3,075 ha. However just 15% of the area had been utilized leaving enough land for future development.

The influence zone of the port covers 13 states in Mexico with an estimated population of 64 million people; none less 50% of the cargo is linked to 3 northern states (Nuevo Leon, Tamaulipas and San Luis Potosi).

A considerable disadvantage with other ports like Manzanillo and Lázaro Cárdenas is the railroad network connectivity which do not aloud double stacking since the existence of tunnels imposes air draft restriction.

Port of Altamira can be considered as the forth most important port in Mexico in terms of throughput, however is considered a young port with full of potential for future development in the long run.

3.5.2 Ensenada

The commercial activity in Ensenada can be traceable to 1928 whit the creation of the Port El Sauzal which mainly activity was fishing. However it was until 1958 when the municipality of Ensenada was founded and it is until 1974 when the port was accredited for ocean going vessels.

The zone of influence is limited to the states of Baja California Sur, Baja California and Chihuahua in Mexico and covers the south part of California and Arizona in United States.

The port of Ensenada have presented continuous growth in containerized cargo, however the activity starts in 1990 when the first container was handled. Today, the port has a total area of 337 hectares and maximum draft of 15 m.

The port of Ensenada is considerable small compare to other ports in Mexico and the region; however port`s activity is strongly linked to the development of the “Maquiladoras” (Cross border assembly plants) in the north part of Mexico.

3.5.3 Lázaro Cardenas

The foundation of the port can be traceable to the beginning of the 1960´s, when the Government constructed a steel factory, the project was planned to be close enough to the sea side for transporting the steel by sea. Consequently the port of Lázaro Cárdenas was developed and since then, the port has been considered as essential promoter of industrialization and investment on the region.

Subsequently, under the administration of the federal monopoly PUMEX and later on with the port reform and the creation of API´s; The Port of Lázaro Cárdenas has been considered one of the most important ports in Mexico for attracting investment estimated in approximately 13 billion dollars, excluding the construction of the steel factory.

Today, the Port of Lázaro Cárdenas has been characterized by been one of the most industrialized areas and the biggest steel producer of the country, within approximately 34% of the total production. In addition, for the last 12 years the port had reach 12% annual growth in terms of cargo handling.

Other advantages of the port are: the navigable waterways which are the largest in the country with 392.34 ha, the accessibility through its channel with 18 m. deep and 16.5 m. of draft restriction in the interior harbours and finally the multimodal corridors (rail and road) which links the port activities with 16 states in Mexico, covering an estimate population of 67 million inhabitants.

Recently the development of an international railroad corridor with double stacking capacity makes feasible the transportation of goods from Lázaro Cárdenas to cities located at the east coast of United States with a population estimated in 125 million people.

At present, the port of Lázaro Cárdenas plays an important role in the intermodal trade between Asia and North America. The port has a specialized double stacking facility for transferring containers into the rail. The development of a corridor, which allows the continuous traffic of containers via Mexico city, State of Mexico, Querétaro, San Luis Potosi, Nuevo Leon and finally Kansa City, Missouri in United States.

One of the disadvantages of the port is that cargo handle are strongly linked to the Industry located at the port and subsequently their terminals are specialized or customized to a narrow range of products. For example: Steel and agro chemical industry (Fertimex). However since 2004 the port experienced a boom in the traffic of containers reaching 590,000 TEU´s in 2009.

3.5.4 Manzanillo

The origins of the commercial activity in Manzanillo can be attributed to the creation of Servicios Porturaios de Manzanillo (SEPORMAN) in 1971. However the modernization of the port is attributable to the creation of the API in 1993.

In 1995 was created the first specialized container terminal been one of the first terminals in Mexico. Today the port of Manzanillo is the most important port in terms of total container throughput concentrating 40% of the total volume.

The port has a total area of 437 hectares and is considered one of the most important in terms of total throughput with a market share of 17%. In addition, occupies the first place in terms of containers, the second place for Mineral cargo, the third place in general cargo and the fifth place for agriculture.

The port covers an influence zone of 15 states and was the first port in implementing double stacking railroad for container cargo. In addition the creation of a commercial corridor between Mexico and United States place the port of Manzanillo as a strong competitor to ports of Los Angeles and Long Beach for attracting containers from Asia.

3.5.5 Progreso

In 1985, the port of Progreso created the infrastructure necessary for receiving ocean going vessels; however the port is considerable small compared to the other ports in Mexico. A positive tendency on cargo traffic flows place the port of Porgreso as an important secondary port.

The port is located in the north part of the Peninsula of Yucatan at 32 km from Merida and well interconnected with the states of Quintana Roo, Tabasco, Campeche and Chiapas.

The port of Progreso has the particularity of being located in a small island 6.4 kilometres inside the ocean; the maximum draft available is 10.34 meters. The facilities include a terminal for cruise ships, a general cargo terminal of 9 hectares with 2.5 hectares for future expansion and a specialized container terminal with 10.8 hectares.

3.5.6 Veracruz

The port of Veracruz is one of the oldest settlements in Mexico. The history of Veracruz is traceable to the arrival of Hernan Cortez in 1519. The port is strongly linked to the history of Mexico; during the colonial period was the gate for importing and exporting goods from and to Spain.

In 1991, Port of Veracruz was the first port in adopting policies which allowed the participation of private investors. However it was until 1993 with the creation of the API when the port authority acquired financial autonomy.

Prior to the port reform of 1993, the port of Veracruz was the most important port in Mexico. Today is the leading port for shipping cars and general agriculture cargo and is the second most important container port of the country.

The zone of influence reaches 60 millions of habitants and covers mainly the states of Veracruz, Puebla, Tlaxcala, Estado de México, Distrito Federal. The port had influenced considerably the development of the city and the nation.

Veracruz has twelve dockage positions with a max draft of 13 m and a restriction of 304 m of length over all (LOA) permitting vessels up to 73,819 DWT. The port of Veracruz is currently expanding its capacity through the participation of public and private investors including a double railroad corridor of 20 km.

4. Hinterland Connectivity

4.1 Introduction

Wang define ports as bi-dimensional logistics systems in which they received goods from ships to be distributed to land (road/rail) and inland waterway modes that perform the remaining legs of the transport system, whereas at the same time ports receive cargoes arriving by road/rail and inland waterway and deliver them to ship for sea-leg. This bi-directional logistics system required high level of coordination and interconnectivity capabilities within the port system.

As state before, one of the main purposes of the seaports is the transhipment of cargo. Thus, the traffic that they handle is directly related to their zones of influence which corresponds to the dynamics of the land they are connected to. Urban zones tend to concentrate economic activities integrating production and consumption systems.

Notteboom and Rodriguez (2000) suggest that the density and extend of hinterland shapes inland freight distribution and port operations and therefore, inland distribution becomes of foremost importance in port competition, favouring the emergence of transport corridors and logistics poles.

An important requirement of a seaport to become a regional or global hub, besides concentrating cargo flows is to expand its hinterland through multimodal integration (Martner, 2002). This chapter gives an overview of the hinterland network in Mexico identifying urban zones or zones with high economic activities which influence seaports development.

4.2 Hinterland Network

Notteboom and Rodriguez stress the importance of global commodity chains, and argue that the landward extensions of these chains from port to gateways are restructuring physical and organizational relationship and hence redefining port hinterland. They suggest that contemporary hinterlands posses macro-economic, physical and logistical dimensions. These dimensions involve different agencies and stakeholders that may be in conflict, therefore implicates different response times to challenges (Wang et al, 2002).

Hinterland transport cost had become relatively important, as the cost per kilogram per kilometer on the hinterland is 5 to 30 times as high (depending on the hinterland transport mode) as the maritime shipping cost (Notteboom, 2008).

There have been some studies for determining the relation between geographical aspects and the development of the country which usually includes variables like distance and transport. For instance Radelet and Sachs (1998) evaluate the relationship between transport cost and national growth, their results showed a clear negative relation between this to variables (Hoffman, 2000); in other words, countries that pay more for the transportation usually present lower rates of growth, in addition exist clear evidence proving that developing countries tend to pay higher cost for transportation than developed countries.

The expansion of the Mexican transportation system had been considerable lower compared with the rest associates countries of the NAFTA (Canada and United States); however the same is strongly related to the geography and economical model adopted in the past.

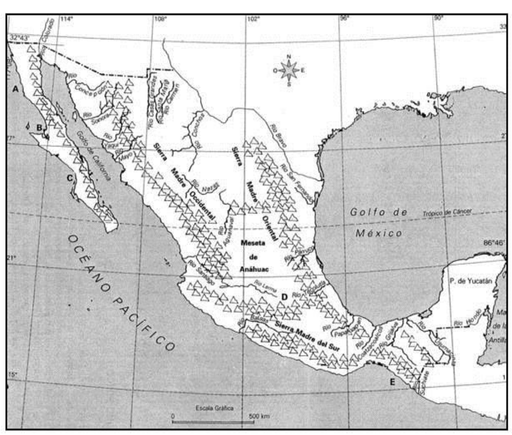
Mexico has a territory of 1,964,375 sq km (Encyclopedia Britannica, 2010). Historically, most of the seaports located in Mexico are considerable new, founded in the twenty century, with few exceptions like: Veracruz, Tampico and Campeche which their foundation are linked to the Spanish colonies on the XVI century.

One of the reasons for the poor progress of hinterland network infrastructure is the accidental orography (figure 8) of the country, which present a boundary of mountains that surrounds the plateau central, where the biggest concentration of population habits, creating a natural barrier from and to the sea side.

During the economic protectionism, port areas of influence were partial and reduced; mainly because of the lack of infrastructure. In general ports activities were limited to exportation of primary goods (Grains and minerals) produced or extract from nearby regions or localities. Moreover, no port competition was possible due the physical barriers (mountains, rivers, etc) that naturally isolated one port from others.

During the past 25 years or so, Mexican government had invested significantly in the development of transversal corridors for interconnecting main ports. Recently, API`s had play an important role in the development of infrastructure, a clear example is the API of Lázaro Cárdenas which recently invested 56 million USD in the construction of the bridge Albatros.

Figure 8: **Mexico´s Orography**



Source: Google images.

De Langen (2008) suggests that port authorities have to become more strongly involved with hinterland access infrastructure and operations. He argues that they can and should become involved because port authorities control decision makings that affect the efficiency of hinterland access, in addition, he believes that that port authorities are obligated introduce better coordination along the supply chain because other private and public parties have weaker incentives to do so (OECD/ITF, 2008).

4.2.1 Railroad Network

The first railroad constructed in Mexico interconnected the port of Veracruz with the capital (Mexico City) in 1857. President Porfirio Díaz fomented the development of railroads infrastructure and attracted foreign private investors; consequently, by the end of 1909 the rail networks covered 24,719 km. In 1909 the government expropriated the rail industry and created a national monopoly Ferrocarriles Nacionales de México (FMN).

According to the Mexican transportation Institute (IMT), today, the operational railroads network covers 23,781 km from which 17,779 km are controlled by the private sector under concessions schemes.

Table 3: **Railroad Concessions by Company**

Company	Railroad covered extension (Km)
Ferrocarrill Mexicano (FERROMEX)	8,357
Kansas City Suthern de Mexico (KCSM)	4,267
FERROSUR	1956
Compañia de Ferrocarriles Chiapas-Mayab	1600
Ferrocarril y terminal del valle de México	356
Others	1243

Source: Author, data from IMT

Figure 9: **Railroad Network by Company**

Source: KCSM

Lately, the transportation of containers by train had become highly competitive reaching importance. In 2008 the railroad system transported 99,692 tons of cargo in containers. In addition, 111,000 TEU´s had for final destination the United States. The average transported distance per container is the 876.1 km (IMT).

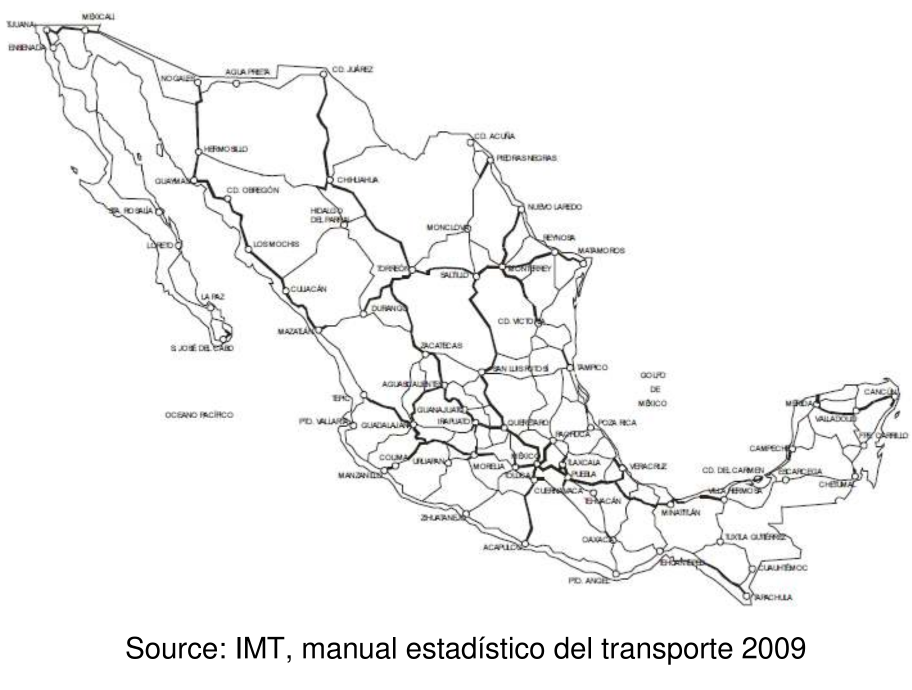
4.2.2 Road Network

The Mexican Institute of Transport estimates in 2007 that the Mexican road network consist of 360,000 km, from which 35% are asphalt roads and the rest do not have any cover or carpet. In addition 91% of the asphalt roads are two carrels wide and the rest four or more.

The roads are administrated either from federal (13.5%), State (20.5%) or locally (66%) governments. However the main network used for multimodal transportation is reduced to 48,000 km, from which 84% are freeways and 16% are highways.

As opposed to many other countries, most cargo exportations are transported by road derived from the fact that Mexico´s main trade flows are to and from United States. This peculiar situation places the maritime industry in a very interesting and unusual competitive position with the road system.

Figure 10 : **Road Network**



Source: IMT, manual estadístico del transporte 2009

4.3 Location as Determinant of Efficiency in Container Ports

The concept of location is associated with various dimensions such as distance to urban areas, population density and richness of the region of influence. The physical location also determines the utilization of land, the waterborne accessibility and the development of hinterland. In addition, H. Haralambides (2010) suggests that "geographical" distance is no longer a good proxy for transport costs in trade models and what one should use is "economic" distance as represented by freight rates.

For many authors, location is considered a determinant of efficiency because of the geographical parameters not only from the port itself but from the area around: for instance a port with a smaller draft will be limited in terms of vessel`s size call and consequently in terms of efficiency due to its inability to accommodate a specific type of vessels.

In addition, some empirical studies using mathematical models where developed for analyzing the effect of port size on port efficiency. For instance, Liu (1995) found that port size is significantly important when explaining port efficiency. Martinez-Budrıa et al. (1999) applied the Data Envelopment Analysis (DEA) to study the relative efficiency of the 26 Spanish port authorities. They showed that ports with larger size are more efficient than the smaller ones (Tongzon and Heng, 2005).

Location per se influences port size hence as productivity is positively correlated with size - this phenomenon is usually known as economies of scale – in case of ports it can be often witnessed that the larger ports are the most productive (Singapore, Hong Kong, Rotterdam for example).

A good example of how location can influence the creation of hub ports are ports located in north Europe, usually referred as Hamburg-Le Havre range which include ports of Hamburg, Bremerhaven, Amsterdam, Rotterdam, Antwerp, Zeebrugge and Le Havre. These ports are located in a strategic position close to a high urbanized and strong economic area. This area is usually known as the blue banana or the hot banana, also some author's reefer to this region as the European megalopolis or European Backbone.

The "blue banana" is a corridor of urbanization in western Europe, with a population around 90 million and covers one of the world`s highest concentrations of people, money and industry. The concept was developed in 1989 by RECLUS, a group of French geographers managed by Roger Brunet (Wikipedia, 2010).

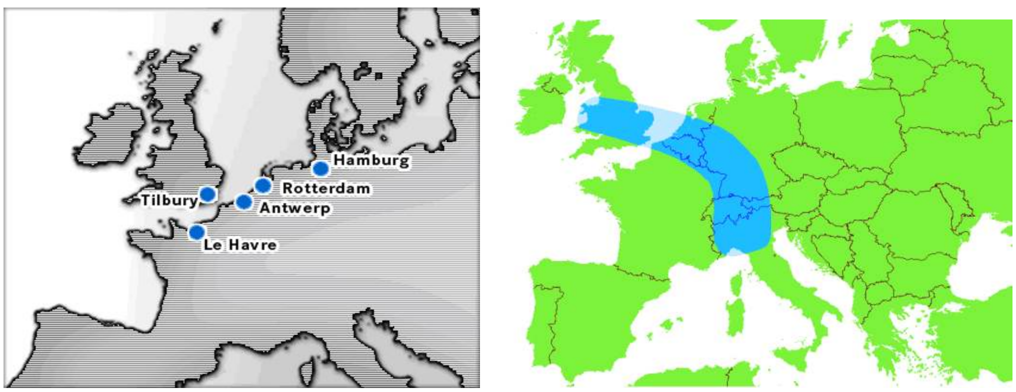
A similar analysis can be carried on other regions of the world and for instance looking at the light pollution of Mexico it appears very clearly that the economic activity is highly-concentrated in the central region of Mexico, including Mexico City and the metropolitan areas together with the area known as "El bajio" which include estates of Guanajuato, Queretaro, Michoacán, in addition San Luis Potosí, Aguas Calientes and some other visibles points are located in Jalisco (Guadalajara), Nuevo Leon (Monterrey) and Yucatan (Merida). However there are just few visible areas located at the coast, more visible are the port of Veracruz and the oil platforms located in the

Campeche. The rest are several less remarkable ¨dots¨ and similarly less economic activity.

Figure 10 show the concentration of population by measuring the light pollution in Mexico and EU. Population concentration is positively correlated to strong economic regions for the simple reason that population demands good and services, thus firms look for locating near highly dense areas for reducing transportation cost.

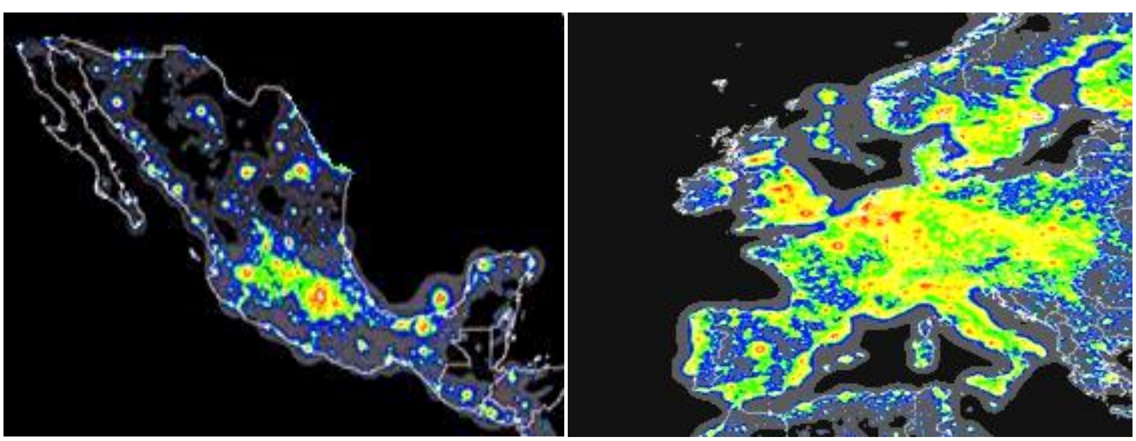
Figure 11 is a map showing the location of the principal ports in Mexico, which can be considerate as a hub ports and their apparent competitive advantage to others ports because of their geographical location which situate this ports close to areas with strong economic development.

Figure 11: **Hamburg-Le Havre range and the Blue Banana.**



Source: Google images.

Figure 12: **Light Pollution in Mexico and EU**



Source: Light Pollution Science and Technology Institute (Italy).

Seaports of Manzanillo and Lázaro Cárdenas (Figure 12) are good example of the importance of geographical location. Both ports are located relatively close, 300 km one to the other and strategically close to the Capital city and the metropolitan area. These ports have become a reliable option for containers coming from Asia to North America because of the existence of an international railroad corridor with double stacking capacity. Furthermore, these ports may be used as alternative route for the congested ports of Los Angeles and Long Beach. These two ports had present great dynamism on container flows with an estimated annual growth of 14% during past ten years.

Figure13: **Hub Ports and Strong Economic Areas**

Source: Author.

Figure 14: **Radial Distance from Chicago to West Coast Seaports.**

Source: Programa Maestro 2006-2012, API Lázaro Cárdenas

5. Research Methodology

5.1 Introduction

This chapter presents information about Data Envelopment Analysis (DEA) and an overview of the theoretical framework including some variants of DEA model. In addition a short recap of the methodology will be presented including its theoretical framework.

The study considers the application of two DEA models the CCR and the BCC. In principle CCR model is build on the assumption of constant returns of scale of activities. However, since the very beginning of the DEA studies, various extensions of the CCR model have been proposed among which the BCC is representative which leads to variable returns to scale.

The chapter includes a short explanation of the inputs and outputs considered and their relevance on the formulation of the model. Finally, the chapter mention possible disadvantages of using DEA methodology.

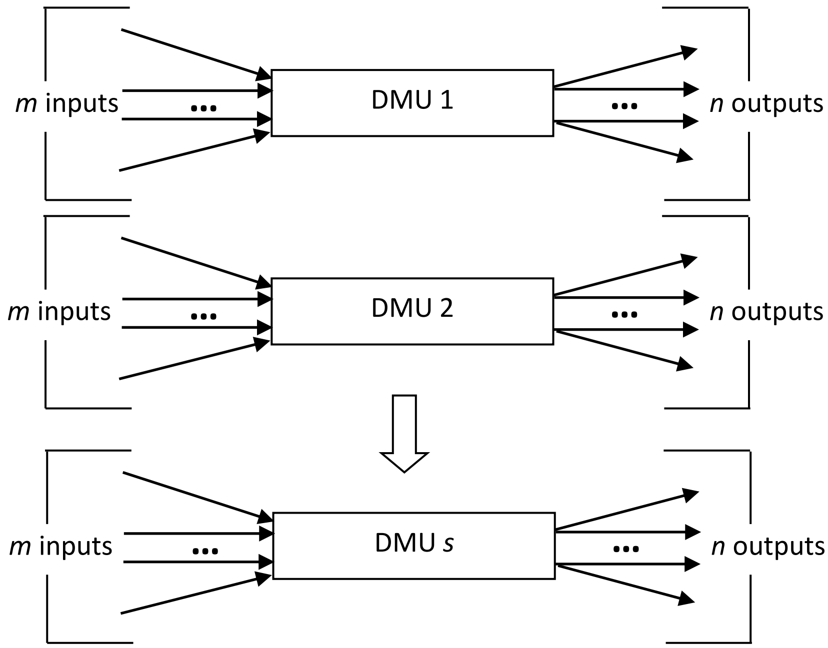
5.2 Data Envelopment Analysis

DEA had become one of the most used tools for monitoring port performance. Charnes et al (1978) were the pioneers in applying and defining DEA´s methodology. Since then many other authors had applied DEA on the transportation sector for measuring efficiency. For instance Baker and Johonston (1994) and Charnes et al (1996) applied DEA in airlines, Oum and YU (1994) in trains..

In general de concept of DEA was conceived from the Engineering point of view, in which the efficiency of a machine (machine / process) can be measure by Output / Input ≤ 1 (Tongzon, 2001).

Wang et al (2002) defined DEA as a nonparametric method for measuring efficiency of a Decision Making Unit (DMU) with multiple inputs and/or multiple outputs. This is achieved by constructing a single virtual input without pre-defining a production functions. The DMU is responsible for controlling the process of production and making strategic decisions at various levels or panoramas (Short-term, long-run, etc). DEA will determine the relatively productivity of a DMU by making a comparison between other homogenous units altering the same into a group of measurable positive inputs into the same type of measurable positive outputs.

Following diagram will exemplify better the DMU and the homogenous variables.



Source: Author based on Wang et al (2002).

Following diagram can be express in the matrixes (1) and (2), where x_{ij}, refers to the i^n input data of DMU_j, and y_{ij} is the i^n outputs of DMU_j.

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots x_{1s} \\ x_{21} & x_{22} & \cdots x_{2s} \\ \vdots & & \\ x_{m1} & x_{m2} & \cdots x_{ms} \end{pmatrix} \qquad (1)$$

$$Y = \begin{pmatrix} y_{11} & y_{12} & \cdots y_{1s} \\ y_{21} & y_{22} & \cdots y_{2s} \\ \vdots & & \\ y_{n1} & y_{n2} & \cdots y_{ns} \end{pmatrix} \qquad (2)$$

However a more scientific formulation of the DEA methodology for measuring efficiency of DMUs with multiple inputs and outpus is the CCR model. The name of the model is given by the authors of the same C (Charnes), C (Cooper) and R(Rhodes) (1978).

The formulation of the CCR model can be expressed by the following equations:

$$(FP_o)Max \qquad \theta = \frac{u_1 y_{1o} + u_2 y_{2o} + \cdots + u_n y_{no}}{v_1 x_{1o} + v_2 x_{2o} + \cdots + v_m x_{mo}} \tag{3}$$

Subject to

$$\frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj}} \leq 1 \qquad (j = 1, \cdots, s) \tag{4}$$

$$v_1, v_2, \cdots, v_m \geq 0 \tag{5}$$

$$u_1, u_2, \cdots, u_n \geq 0 \tag{6}$$

The inputs weights v_n and the outputs weight u_m are variables to be obtained taking into account equation (4), which reveals that ratio of virtual output to virtual input cannot exceed 1. Furthermore, the equation confirms the assumption that outputs cannot exceed inputs in the production function.

The above FP (3)-(6) is equivalent to the following linear programming (LP) formulation given in equations (7)-(11) (see e.g. Cooper et al, 2000):

$$(LP_o)Max \qquad \theta = u_1 y_{1o} + u_2 y_{2o} + \cdots + u_n y_{no} \tag{7}$$

Subject to

$$v_1 x_{1o} + v_2 x_{2o} + \cdots + v_m x_{mo} = 1 \tag{8}$$

$$u_1 y_{1j} + u_2 y_{2j} + \cdots + u_n y_{nj} \leq v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj} \qquad (j = 1, \cdots, s) \tag{9}$$

$$v_1, v_2, \cdots, v_m \geq 0 \tag{10}$$

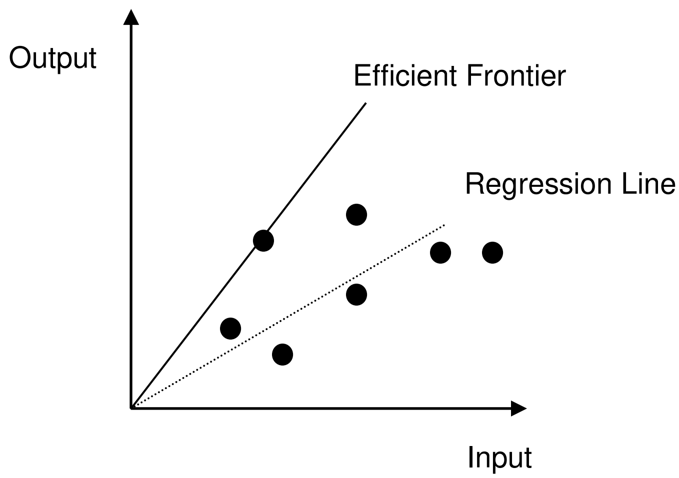
$$u_1, u_2, \cdots, u_n \geq 0 \tag{11}$$

DEA analysis is considered as very flexible and useful methodology available because of its particularity of been able to transform the problem into a Liner Programming form. This characteristic adds flexibility doing possible its implementation in wide range of applications.

DEA aims to calculate a frontier based on Pareto efficient units. The efficient frontier will be determine by the highest slope from the origin possible. Differentiating DEA an liner regressions is simple, Liner regression use the principle of least square finding a liner equation that most likely will describe the behaviour of the variables, while DEA determinates a frontier between the most efficient points evolving the rest.

For a better understanding, Cooper et al (2006) exemplify the difference between the regression line and DEA in the following illustration:

Figure 15: **Regression Line vs Efficient Frontier.**



Source: Cooper et al (2006)

There are some variants on the DEA analysis, however the most commonly used for evaluating seaports efficiency are CCR model and the BCC. For instance, CCR points out differences among DMUs most extremely than the others. There are two possibilities of formulating the CCR model. The first one focuses on minimizing resources or Inputs, while the second focuses on maximizing outputs.

There are not strict rules for choosing indistinctly each of these approaches, however in some applications the inputs are inflexible, and therefore an output approach would be more suitable. A characteristic of the CCR model is that either formulations or orientations (input or output) will yield identical results, this model is based on the classical definition of efficiency as “Engineering ratio”.

The BCC model takes into account the effect of returns to scale (outputs increase more than the proportional change). In other words, DEA BBC analyses what would happen as the scale of production increases in the long run. BBC model is characterized by considering increasing returns to scale occurring in the first solid line segment follow by decreasing returns to scale in the second segment and finally constant returns to scale occurring at the point where the transition from the first to second segment is made.

The BBC model yields in different results according to the input or output formulation. The models differ basically in their envelopment surface orientation and projection path. For the purpose of the study, both models CCR and BCC will be taken into account.

5.3 Data Collection and Formulation

For performing any kind of comparison is recommendable to compare similar things otherwise would be inappropriate; for instance trying to compare apples and pears. In the same context comparing seaports require to select comparable ports. This is the reason why many authors focus on comparing containers terminals which are highly standardized in their process and leave apart the overall port performance comparisons. However this study will focus in overall productivity measuring changes on technical efficiency.

For determining which seaports would be included in this study was necessary to select those ports sharing similarities, for instance one of the criteria was to select just those ports which have specialized container terminals. Therefore, ports like Tampico and Mazatlan were disqualified. All of the six ports here included in the study can handle general and containerized cargo.

The selection of inputs and outputs is also important. According to the economic theory, the efficient use of land, labour and capital are critical (Efficiency in and put).
However, Notteboom et al (2000) claim that port labour can be measured through other capital inputs variables such as Berth and quay length, terminal area and cranes.

For the purpose of this study, were selected three inputs:

1) Total length of berth in square meters.
2) Total Storage area for general and containerized cargo in square meters.
3) Number of cranes which include all types and kind of cranes available for handling either containers or general cargo.

The outputs are:

1) Total containers throughput in TEUs.
2) Total general cargo throughout in tons.

Input variables are mainly concerned with physical characteristics which are considered the most widely used input measures for DEA methods. For instance Berth length is included as a measure of productivity on the sea-short side. Storage area reflects yard capacity for containers and storage capacity for general cargo. Number of cranes include: Quay cranes, shore cranes, mobile cranes, etc. All types of cranes are included, since cranes are the most expensive equipment available and can reflect the size of labour working in each of the ports.

The period of the analysis covers from year 2002 to 2009. The data was collected mainly through the Mexican Institute of Transport (IMT) and actualized directly with the APIs of each port.
The summary statistics for inputs and outputs are provided in figure 17:

Table 4: **Summary Statistics for Sample**

	Tons	*TEU's*	*Berth Length*	*Storage Area*	*Cranes*
Mean	10971631	390781.6	2253.75	411269.875	30.95833
Standard Error	953924.5	54669.62	153.2578325	54825.99783	4.801185
Median	13336564	283472.5	2082	369752	15.5
Mode	#N/A	#N/A	2381	784810	13
Standard Deviation	6608982	378762.2	1061.80141	379845.6553	33.26359
Kurtosis	-1.49945	0.749589	-0.782954378	0.497698584	2.982936
Skewness	-0.19066	1.133642	0.300364566	1.048270111	2.072866
Range	21000484	1411012	3307	1312355	113
Minimum	1294516	134	722	7398	6
Maximum	22295000	1411146	4029	1319753	119
Count	48	48	48	48	48

Source: Author from own calculations.

5.4 Potential Disadvantages of DEA

Ray (2002) affirm that the lack of allowance for statistical noise is the most serious limitation of DEA analysis because creates serious pressure on users to collect data on all relevant variables and to measure them accurately (Wang et al, 2002).

The fact that the efficient frontier is based on best observed units is also a limitation of the model since probably more efficient observed data is not absolutely efficient. In addition, the virtual ratios (of output and inputs) created by DEA are based on the sum of weighted outputs divided by the sum to the weighted inputs. However can be questionable the validity of using ratios based on different units.

Moreover, Wang et al (2002) point out the principle that weights for outputs and inputs are obtained by calculating DEA model, rather than being given artificially, and therefore is believed that the data would be only influenced by the same data and therefore weights can be mislead.

6. Results and Analysis

6.1 Introduction

This chapter presents the results obtained by estimating seaport efficiency from the data obtained from six container ports in Mexico over eight years period. The sample consist of forty eight measures and the methodology used was DEA CCR and DEA BBC, both output oriented.

The aim of the study is to find whereas ports handling more cargo or total throughput are also ports operating under higher technical efficiency or not.

6.2 Efficiency Scores based on CCR model

This section present the results of all DMU`s based on DEA-CCR model which is based on the classical definition of efficiency. DEA-CCR points out differences among DMUs most extremely than DEA-BCC.

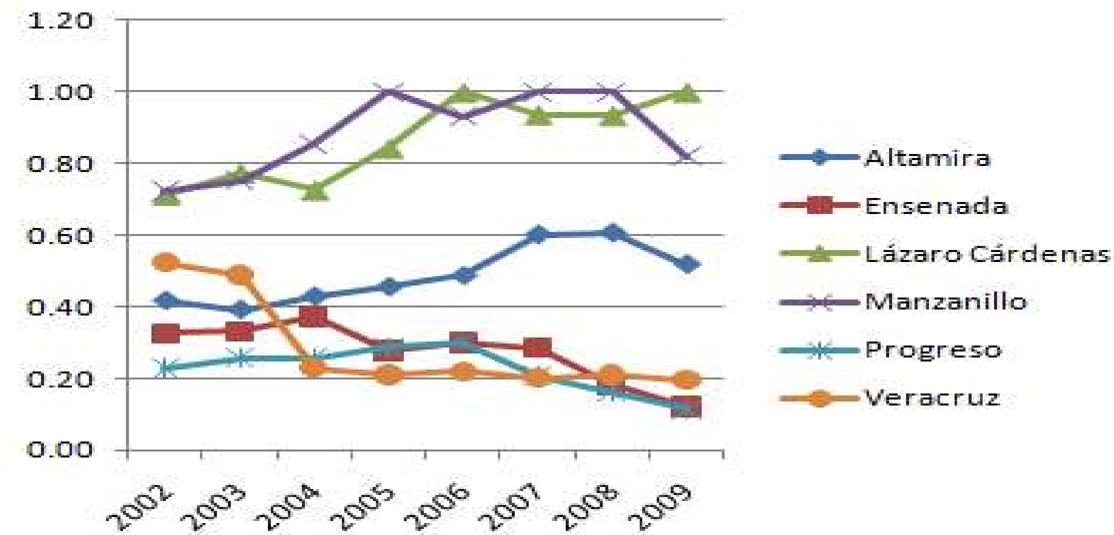
Table 5: **Results obtained using DEA-CCR model (output based)**

Year	Altamira	Ensenada	Lázaro Cárdenas	Manzanillo	Progreso	Veracruz
2002	0.42	0.32	0.71	0.72	0.23	0.52
2003	0.39	0.33	0.77	0.75	0.26	0.49
2004	0.43	0.37	0.73	0.85	0.26	0.23
2005	0.46	0.28	0.84	1.00	0.29	0.21
2006	0.49	0.30	1.00	0.93	0.30	0.22
2007	0.60	0.29	0.94	1.00	0.21	0.20
2008	0.61	0.18	0.93	1.00	0.16	0.21
2009	0.52	0.12	1.00	0.82	0.11	0.20
Mean	**0.49**	**0.27**	**0.87**	**0.88**	**0.23**	**0.29**

Source: Author

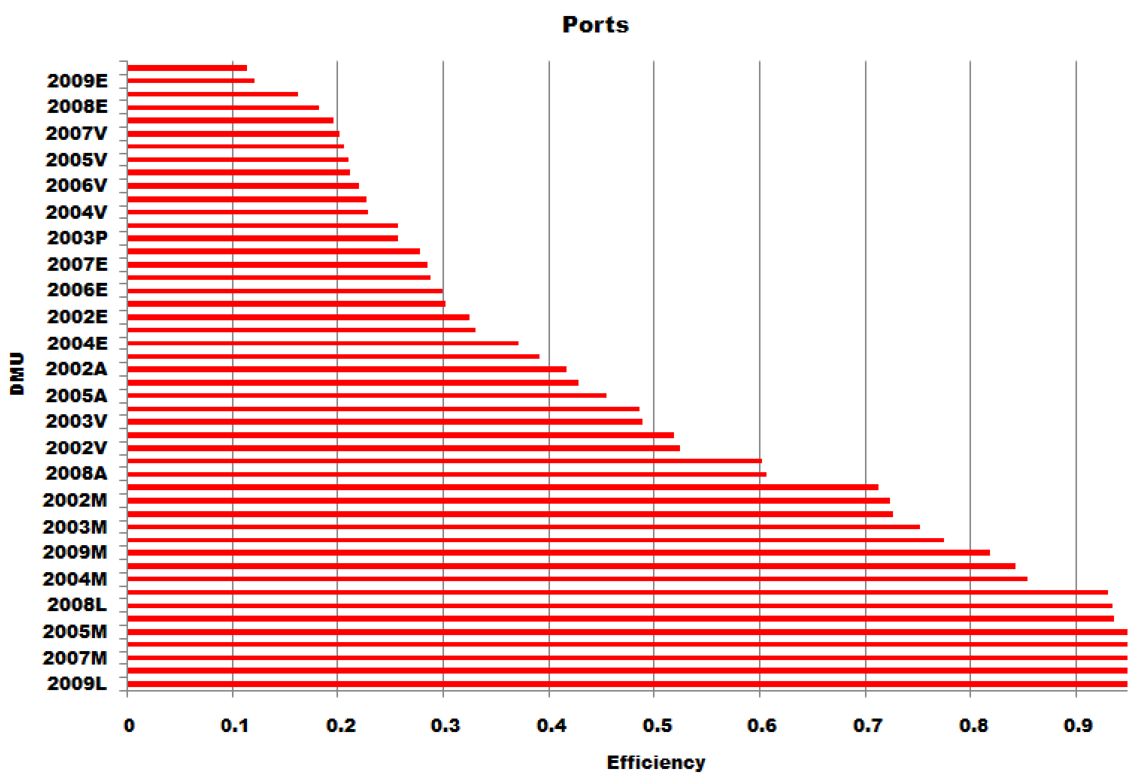
The result obtained under CCR Model output oriented indicates that seaports operating relatively more efficient are Manzanillo and Lázaro Cárdenas.
Figure 17 shows the results obtain graphically in a time line chart. It is evident that ports of Veracruz, Ensenada and Progreso need to improve their operations since they ratio of efficiency is relatively lower and follows a negative tendency.
Figure 18 is a bar chart of DEA scores in the ascending order which is useful for identify what are the DMUs operating efficiently. The CRR model presents five optimum points: Manzanillo (2005, 2007 and 2008) and Lázaro Cárdenas (2006, 2009).

Figure16: **Efficiency Changes Based on DEA CCR Model**



Source: Author

Figure 17: **Bar Chart of DEA CCR Scores in the Ascending Order**



Source: Author

6.2.1 Scores and Slacks on DEA CCR model by Seaport

Slack show the output shortfalls and inputs surplus associated with examined DMU in addition to the increase of all outputs by a factor equal to the efficiency score.

Altamira

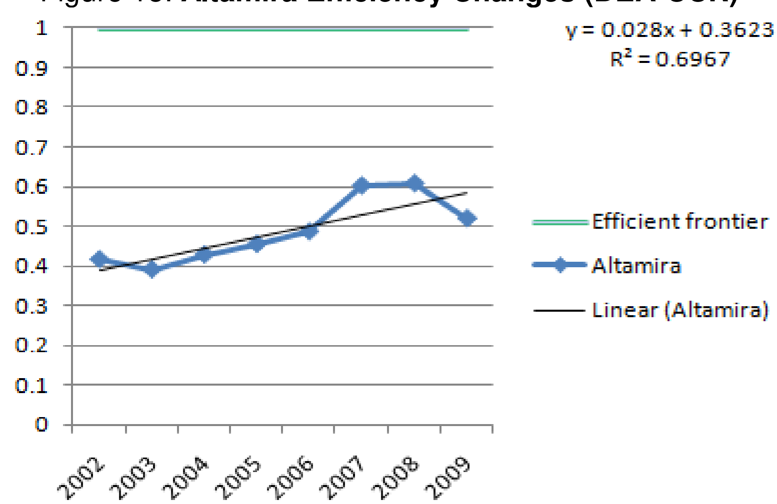
Table 6 show the scores of the DMU associated to the port of Altamira, as well as the slacks. It is evident that the port of Altamira presents excess on Storage Area. In figure 19 is possible to appreciate the behaviour of efficiency from years 2002 to 2009.

Table 6: **DMU Scores and Slacks of Altamira (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002A	0.416411	0	441607.4	0	0	0
2003A	0.391283	0	455676.4	0	0	0
2004A	0.428335	0	460343.1	0	0	0
2005A	0.455011	0	465812.5	0	0	0
2006A	0.48636	0	478912.3	0	0	0
2007A	0.601765	0	467407	0	0	0
2008A	0.60702	0	478669	0	0	0
2009A	0.519347	0	477198.3	0	0	0
Mean	**0.488192**	**0**	**465703.3**	**0**	**0**	**0**

Source: Author

Figure 18: **Altamira Efficiency Changes (DEA-CCR)**



Source: Author

Ensenada

Ensenada present excess on Berth length and shortfall on TEU, however in year 2006 and 2007 the port had presented grater dynamism of containers flows which are reflected in DEA analysis in years 2007 and 2008. However the economic downturn affects such dynamism reducing containers flows in years 2008 and 2009 which are also visible in table 7.

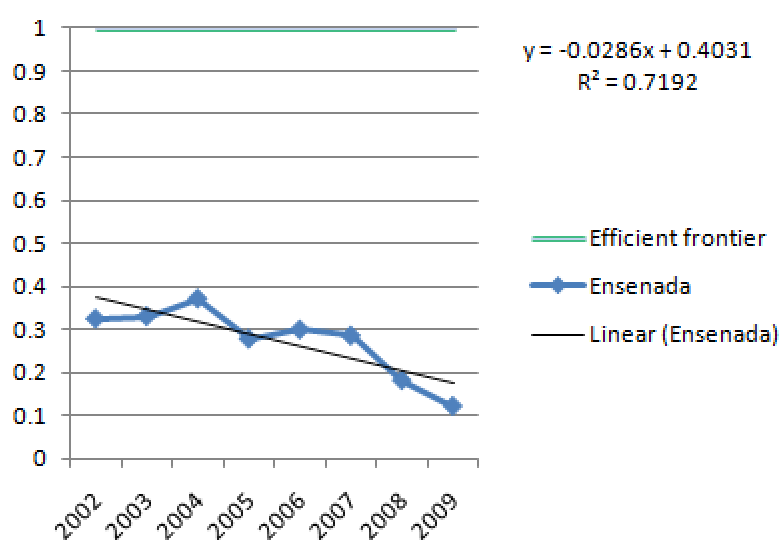
Figure 20 helps to evidence the negative tendency of technical efficiency.

Table 7: **DMU Scores and Slacks of Ensenada (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002E	0.324887	1104.155	0	0	0	3274.945
2003E	0.330608	1049.816	0	0	0	96782.8
2004E	0.371635	1049.816	0	0	0	131439.2
2005E	0.278281	913.9671	0	0	0	142246.2
2006E	0.299491	886.7974	0	0	0	34089.67
2007E	0.285449	916.3232	0	0	0	0
2008E	0.181625	919.2272	0	0	0	0
2009E	0.121602	913.9671	0	0	0	19422.68
Mean	**0.274197**	**969.2586**	**0**	**0**	**0**	**53406.94**

Source: Author

Figure 19: **Ensenada Efficiency Changes (DEA-CCR)**



Source: Author

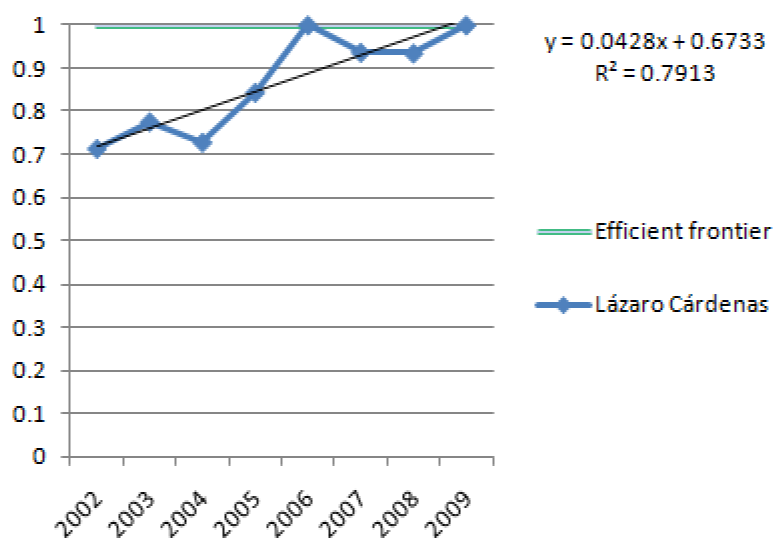
Lázaro Cárdenas
Port of Lázaro Cárdenas presents high efficiency levels, however slacks show an excess of storage capacity and lack of container flows from 2002 to 2005, which indicates that the model describes the reality since the specialized container terminal was inaugurated in 2004 reverting the shortfall.
Figure 21 evidence the positive tendency on technical efficiency.

Table 8: **DMU Scores and Slacks of Lázaro Cárdenas (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002L	0.712284	0	876908	0	0	310106.9
2003L	0.774829	0	876908	0	0	308170.7
2004L	0.726908	0	867506	0	0	175878.7
2005L	0.843196	0	876908	0	0	153179.6
2006L	1	0	0	0	0	0
2007L	0.9366	0	721.167	0	0	0
2008L	0.93448	0	1323.131	0	0	0
2009L	1	0	0	0	0	0
Mean	**0.866037**	**0**	**437534.3**	**0**	**0**	**118417**

Source: Author

Figure 20: **Lázaro Cárdenas Efficiency Changes (DEA-CCR)**



Source: Author

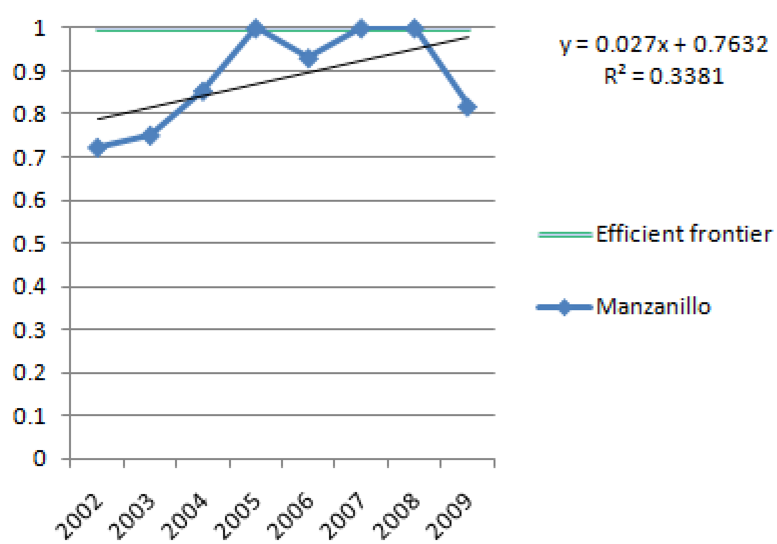
Manzanillo
Manzanillo is the port that presents higher technical efficiency levels. Also, the port does not present any excess in selected inputs, contrary to the rest of the analyzed ports. Port of Manzanillo is the most congested port in terms of containers throughput. The API of Manzanillo forecast reaching its maximum capacity by 2020.
In table 9 the shortfall of TEUs in year 2009 are caused by the reduction on containerized cargo on 2008 and 2009 caused by the economic downturn.

Table 9: **DMU Scores and Slacks of Manzanillo (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002M	0.723715	0	0	0	0	158059.3
2003M	0.751816	0	0	0	0	98047.61
2004M	0.854339	0	0	0	0	2101.062
2005M	1	0	0	0	0	0
2006M	0.930704	0	0	0	0	0
2007M	1	0	0	0	0	0
2008M	1	0	0	0	0	0
2009M	0.818479	0	0	0	0	53173.77
Mean	**0.884882**	**0**	**0**	**0**	**0**	**38922.72**

Source: Author

Figure 21: **Manzanillo Efficiency Changes (DEA-CCR)**



Source: Author

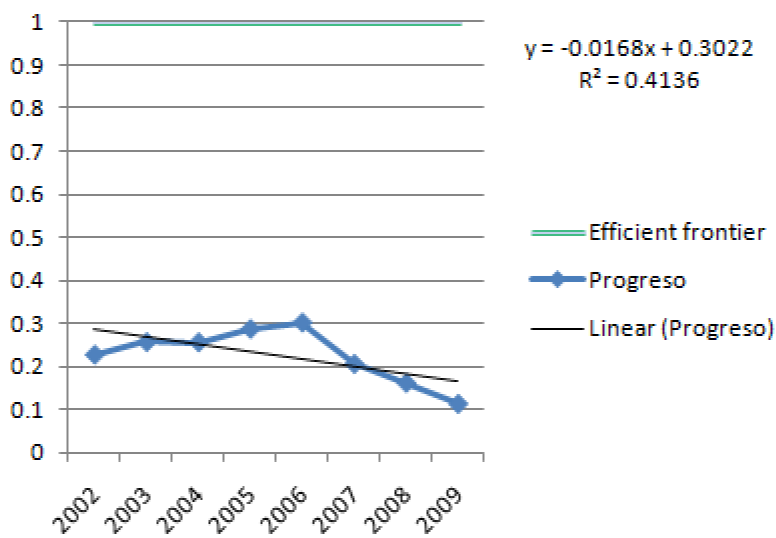
Progreso
Port of Progreso exhibits a slightly negative tendency on efficiency show on figure 23 and a mix result of slacks/Excess. More significantly are the excess in storage area and the shortage on Containers throughput.

Table 10: **DMU Scores and Slacks of Progeso (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002P	0.227825	0	103195.3	0	0	143565.2
2003P	0.25702	0	68734.28	0	0	110760.2
2004P	0.256532	0	10009.28	0	0	80024.48
2005P	0.2876	0	10009.28	0	0	95874.3
2006P	0.302344	0	5308.294	0	0	56849.97
2007P	0.206331	56.45077	0	0	0	0
2008P	0.16203	0	783.6696	0	0	0
2009P	0.113589	10.81549	0	0	76507.19	0
Mean	**0.226659**	**8.408283**	**24755.01**	**0**	**9563.399**	**60884.27**

Source: Author

Figure 22: **Progreso Efficiency Changes (DEA-CCR)**



Source: Author

Veracruz

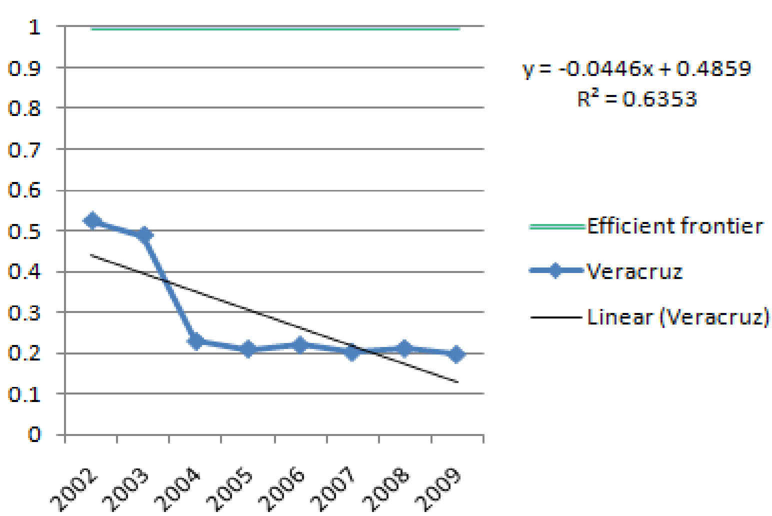
Veracruz had been presenting a strong fall on technical efficiency between years 2003 and 2004, after this year figure 24 shows a more stable behaviour. However this deep fall is attributable to the expansion of the terminals realized in years 2005 and 2006. Port authorities may change strategy for revert the relatively stately tendency on efficiency visible in figure 24. Also port of Veracruz will need to find its way for attracting more containers since present a shortfall of TEUs.

Table 11: **DMU Scores and Slacks of Veracruz (DEA-CCR)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002V	0.523867	734.9264	0	0	0	0
2003V	0.488391	586.264	0	0	0	0
2004V	0.229065	0	184399.6	0	0	549027.4
2005V	0.21029	566.8353	0	0	0	1160702
2006V	0.219645	0	301924.3	0	0	992854.9
2007V	0.202164	0	306625.3	0	0	493197.8
2008V	0.211452	0	306625.3	0	0	716407.5
2009V	0.196746	0	306625.3	0	0	1234495
Mean	**0.285203**	**236.0032**	**175775**	**0**	**0**	**643335.6**

Source: Author

Figure23: **Veracruz Efficiency Changes (DEA-CCR)**



Source: Author

6.3 *Efficiency Scores based on BBC model*

Results of DEA-BBC analysis are presented in table 12. DEA-BBC results differs from DEA-CCR since the model takes into account the effect of returns to scale (outputs increase more than the proportional change). BBC model is characterized by considering increasing returns to scale occurring in the first solid line segment follow by decreasing returns to scale in the second segment and finally constant returns to scale occurring at the point where the transition from the first to second segment is made.

Table12: Results obtained by analysing DEA-BBC (output oriented)

Year	Altamira	Ensenada	Lázaro Cardenas	Manzanillo	Progreso	Veracruz
2002	0.42	1.00	0.77	0.72	0.33	0.71
2003	0.40	0.64	0.84	0.75	0.37	0.73
2004	0.44	0.72	0.76	0.85	0.37	0.69
2005	0.48	0.36	0.92	1.00	0.41	0.74
2006	0.54	0.37	1.00	0.93	0.48	0.80
2007	0.64	0.36	0.94	1.00	0.40	0.74
2008	0.68	0.23	0.94	1.00	0.25	0.77
2009	0.57	0.16	1.00	0.82	0.17	0.72
Mean	**0.52**	**0.48**	**0.90**	**0.88**	**0.35**	**0.74**

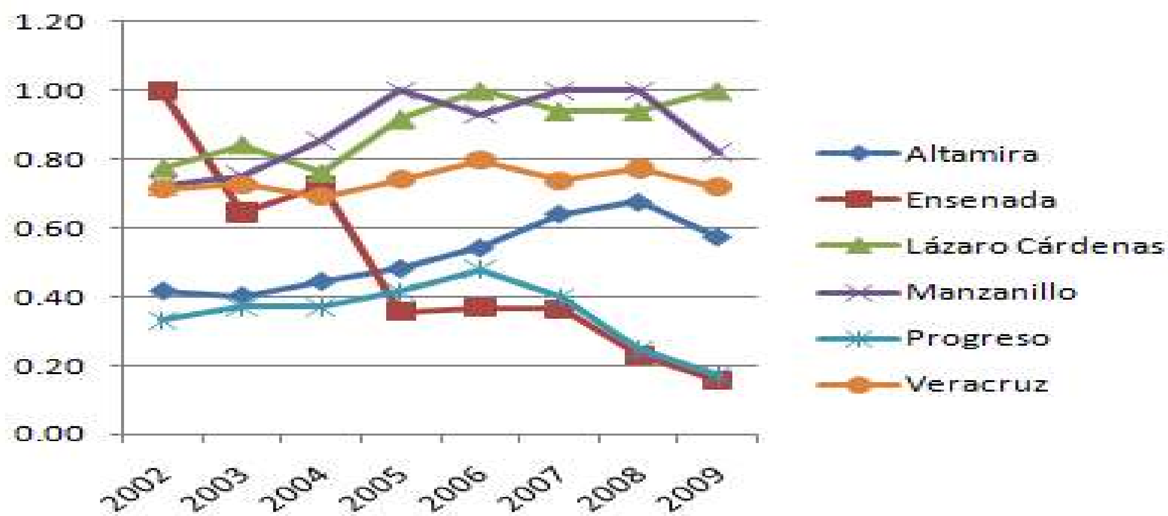
Source: Author

The result obtained by DEA-BBC Model output oriented coincides with results of DEA-CCR model; In both cases seaports operating relatively more efficient are Manzanillo and Lázaro Cárdenas.

Figure 25 illustrates the efficiency changes based on BCC results. It is remarkable how Veracruz and Progreso enhanced their efficiency results compared to the CCR model. Figure 26 is a bar chart of DEA BBC scores in the ascending order which is useful for identify what are the DMUs operating efficiently. The BCC model presents six optimum points: Ensenada 2002, Manzanillo (2005, 2007 and 2008) and Lázaro Cárdenas (2006, 2009).

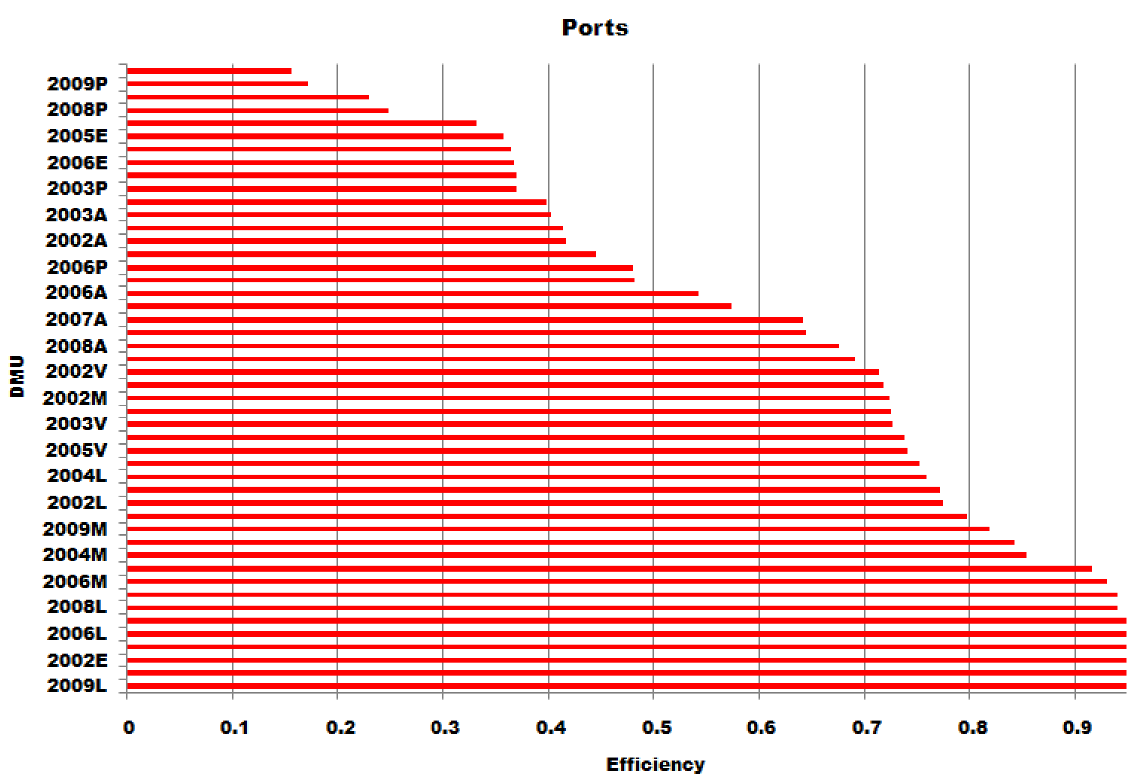
Figure 26 illustrate DMUs with lower and higher efficiency index. Lazaro Cardenas in years 2006, 2008, 2009 operated relatively more efficient. Contrary to this, ports of Progreso (2009,2008) and Ensenada (2005,2006) underperform.

Figure 24: **Efficiency Changes Based on DEA BBC Model**



Source: Author

Figure 25: **Bar Chart of DEA BBC Scores in the Ascending Order**



Source: Author

6.3.1 Scores and Slacks on DEA BBC model by Seaport

Altamira

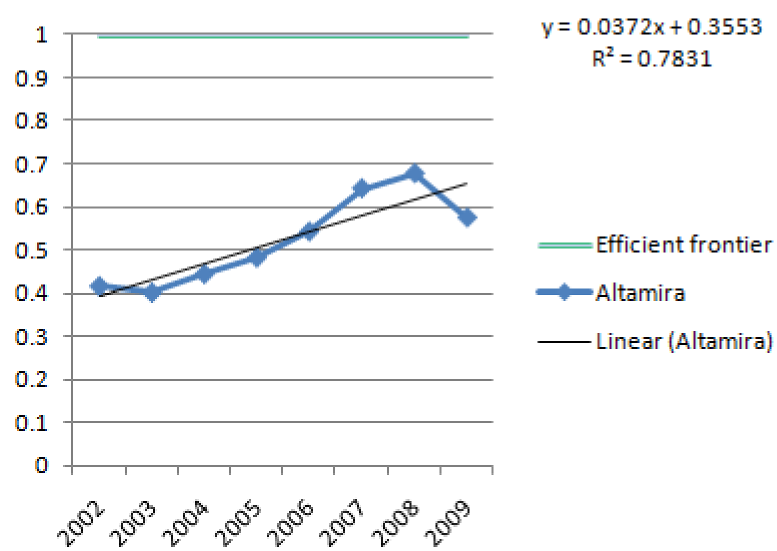
Port of Altamira exhibits a positive tendency in efficiency with some excess in Storage are available and length of berth.

Table 13: **DMU Scores and Slacks of Altamira (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002A	0.416735	0	441971.9	0	0	0
2003A	0.402607	0	441731.6	0	0	0
2004A	0.444526	0	441731.6	0	0	0
2005A	0.482082	91.75405	460297.1	0	0	0
2006A	0.54224	312	504861.4	0	0	28583.79
2007A	0.641663	119.7205	465955.8	0	0	0
2008A	0.675961	312	504861.4	0	0	22900.11
2009A	0.5745	303.6414	503170.1	0	0	0
Mean	**0.522539**	**142.3895**	**470572.6**	**0**	**0**	**6435.488**

Source: Author

Figure 26: **Altamira Efficiency Changes (DEA-BBC)**



Source: Author

Ensenada

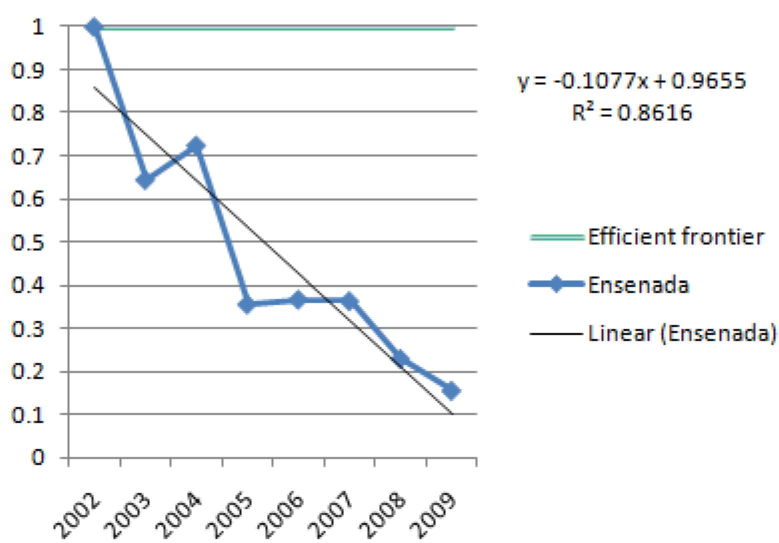
Ensenada presents a deep collapse of port technical efficiency, this is evident in figure 28. In addition, the existence of shortage in TEUs indicates that port of Ensenada can handle more containers based on its resources. An increase in throughput will have a positive impact in overall productivity.

Table 14: **DMU Scores and Slacks of Ensenada (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002E	1	0	0	0	0	0
2003E	0.644729	79.69864	0	0	0	65160.88
2004E	0.724736	79.69864	0	0	0	82932.18
2005E	0.356994	278.903	0	0	0	136352.7
2006E	0.367815	318.7439	0	0	0	52322.47
2007E	0.364352	278.903	0	0	0	16481.89
2008E	0.230389	278.903	0	0	0	5278.564
2009E	0.155998	278.903	0	0	0	40610.41
Mean	**0.480627**	**199.2191**	**0**	**0**	**0**	**49892.39**

Source: Author

Figure 27: **Ensenada Efficiency Changes (DEA-BBC)**



Source: Author

Lázaro Cárdenas

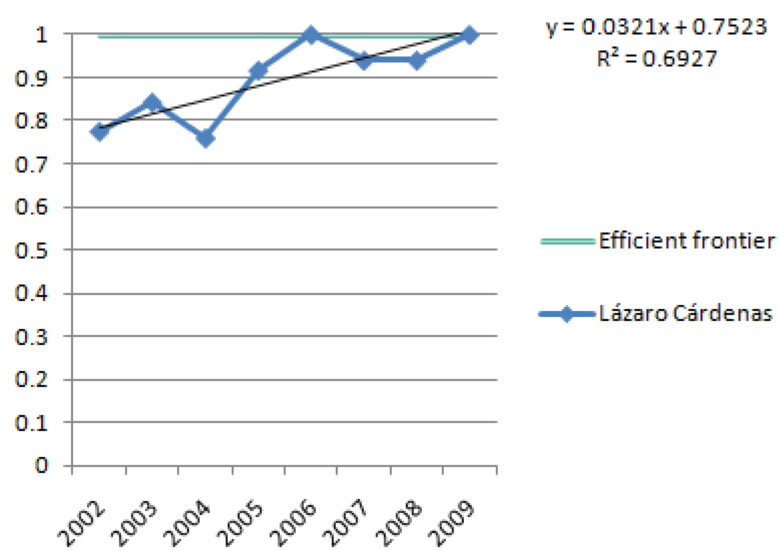
DEA-BBC model determinates that port of Lázaro Cárdenas is the most efficient port firm the sample, therefore we can say that in the long run Lázaro Cárdenas is even more efficient than Manzanillo. The lack of a specialized container terminal in years 2002, 2003 and 2004 are evident, however with the opening of the same in 2004 the shortage of TEUs is reverted. Exist some degree of excess capacity in Storage area and berth lengths.

Table 15: **DMU Scores and Slacks of Lázaro Cárdenas (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002L	0.774384	299.3333	918670.8	0	0	327327.8
2003L	0.842382	299.3333	918670.8	0	0	325546.8
2004L	0.759078	149.6667	888387.4	0	0	187014.5
2005L	0.916709	299.3333	918670.8	0	0	182985
2006L	1	0	0	0	0	0
2007L	0.939738	12.67158	2563.954	0	0	0
2008L	0.940113	24.42375	4941.877	0	0	0
2009L	1	0	0	0	0	0
Mean	**0.896551**	**135.5952**	**456488.2**	**0**	**0**	**127859.3**

Source: Author

Figure 28: **Lázaro Cárdenas Efficiency Changes (DEA-BBC)**



Source: Author

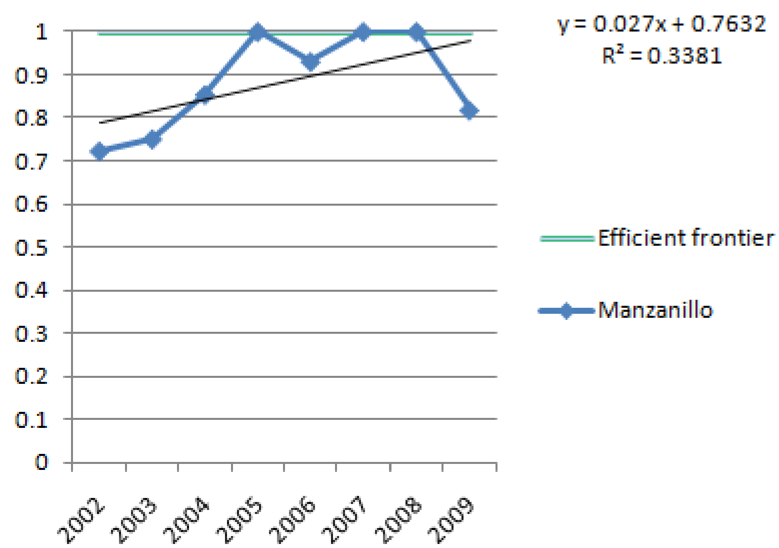
Manzanillo
Differently from the CCR model, the BBC model place Manzanillo as the second more efficient port in Mexico. Again no excess in inputs is presented.

Table 16: **DMU Scores and Slacks of Manzanillo (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002M	0.723715	0	0	0	0	158059.3
2003M	0.751816	0	0	0	0	98047.61
2004M	0.854339	0	0	0	0	2101.062
2005M	1	0	0	0	0	0
2006M	0.930704	0	0	0	0	0
2007M	1	0	0	0	0	0
2008M	1	0	0	0	0	0
2009M	0.818479	0	0	0	0	53173.77
Mean	**0.884882**	**0**	**0**	**0**	**0**	**38922.72**

Source: Author

Figure 29: **Manzanillo Efficiency Changes (DEA-BBC)**



Source: Author

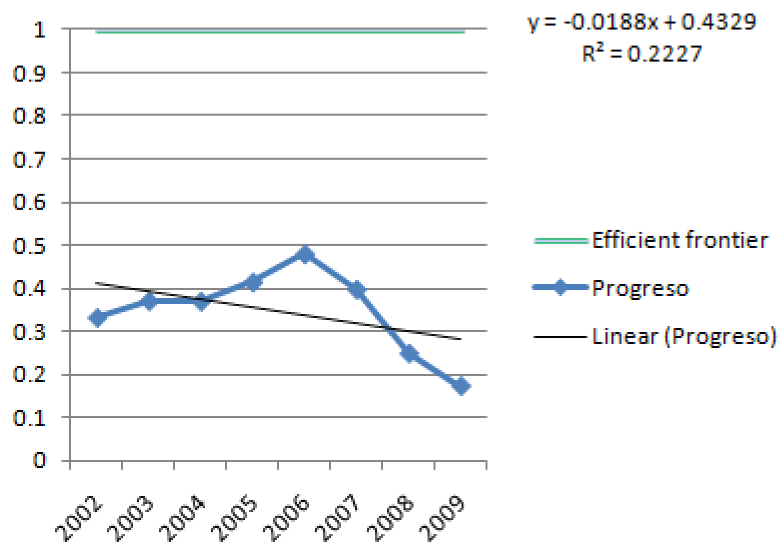
Progreso
Port of Progreso exhibits low levels of efficiency and a negative tendency with excess of storage capacity and lack of container traffic.

Table 17: **DMU Scores and Slacks of Progreso (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002P	0.331892	0	199005	0	0	212653.7
2003P	0.370585	0	163423.9	0	0	172348.7
2004P	0.36988	0	104698.9	0	0	151031.9
2005P	0.414677	0	104698.9	0	0	162024.6
2006P	0.480664	0	115425.2	0	0	138054.7
2007P	0.398169	0	136877.9	0	0	28248.34
2008P	0.248196	0	115425.2	0	0	28249.38
2009P	0.172026	0	116965.9	0	0	0
Mean	**0.348261**	**0**	**132065.1**	**0**	**0**	**111576.4**

Source: Author

Figure 30: **Progreso Efficiency Changes (DEA-BBC)**



Source: Author

Veracruz

Is remarkable the difference on estimations of Veracruz technical efficiency provided by BBC model compared to the relatively negative results of the CCR model.

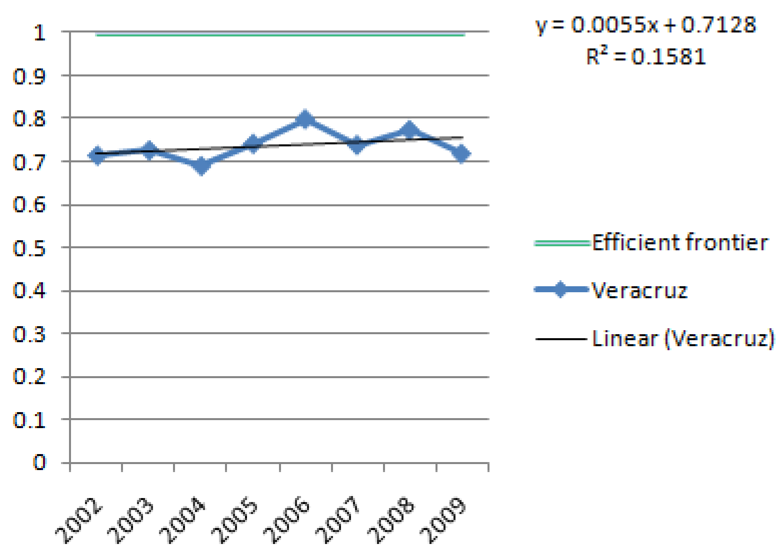
Figure 32 evidence a staidly but positive efficiency; however the excess of storage capacity, length berth and cranes show an excess of resources and shortage of container flows.

Table 18: **DMU Scores and Slacks of Veracruz (DEA-BBC)**

DMU	Score	Excess L_Berth S-(1)	Excess Stg_a S-(2)	Excess Cranes S-(3)	Shortage Tons S+(1)	Shortage TEU S+(2)
2002V	0.714527	2409	255219.6	0	0	142735.8
2003V	0.726235	2783.167	330928.1	0	0	330958.4
2004V	0.690869	3307	436920	52	0	553272.1
2005V	0.741337	3307	36920	77	0	572297.8
2006V	0.797067	3307	436920	77	0	563088.2
2007V	0.738585	3307	436920	78	0	421788.2
2008V	0.772519	3307	436920	78	0	482884.6
2009V	0.718791	3307	436920	78	0	624694.1
Mean	**0.737491**	**3129.271**	**350958.5**	**55**	**0**	**461464.9**

Source: Author

Figure 31: **Veracruz Efficiency Changes (DEA-BBC)**



Source: Author

6.4 Analysis of Results

It is evident that exist shortage of TEU`s flow in 52% of the DMUs based on the sample; which leads to the general conclusion that Mexico`s port system need to implement strategies for getting more containers traffic.

Second observation is that the excess in inputs are mainly related with storage capacity and length berth. However port of Manzanillo will reach its maximum storage capacity by the year 2020. The results of DEA-CCR and DEA-BBC do not present any excess in storage capacity; furthermore the model is able to describe (at some point) the reality.

Third observation is that Ports of Lázaro Cárdenas and Manzanillo operate under higher efficiency leading to the conclusion that the rest of the ports need to implement strategies for caching up same levels of efficiency in order to compete.

Table 19 summarizes the results obtained. The mean obtained in CCR model is 0.50 and the mean obtained in BBC model is 0.64. Estimating the mean, we can say that the average overall container ports efficiency in Mexico is estimated in 0.57.

Table19 :**Summary Statistics of DEA CCR and DEA BCC**

	CCR	*BCC*
Mean	0.504195	0.645058
Standard Error	0.042503	0.036121
Median	0.422373	0.716659
Mode	1	1
Standard Deviation	0.294467	0.250251
Sample Variance	0.086711	0.062625
Kurtosis	-1.25213	-1.06815
Skewness	0.473996	-0.2385
Range	0.886411	0.844002
Minimum	0.113589	0.155998
Maximum	1	1
Sum	24.20135	30.9628
Count	48	48

Source: Author

Virtual Weights are also known as the virtual multipliers for the examined DMUs. Applying these factors to each of the DMUs will provide its best relatively efficiency score. These weights are provided in Appendix 1 and 2.

Conclusions

The first conclusion is that as a result of measuring seaports technical efficiency by DEA CCR and DEA BBC, the most efficient ports are Port of Lázaro Cárdenas and Manzanillo.

Second, all results obtained by both methods are similar; however the port of Veracruz presents much higher index of efficiency by DEA-BCC method which leads to the conclusion that in the long run the port operates under better levels of efficiency than in the short run.

Third, based on the evidence we can conclude that container ports operating more efficiently are those attracting higher levels of traffic. Table 19 shows the final efficiency scores obtained by both methodologies and the mean, also include the ranking accordingly to total throughput. Even though the rank do not precisely match with the scores obtained by the efficiency analysis. The study concludes that the first three more efficient ports are the three with higher market share, similarly behaviour is observed on the less efficient ports.

Table 20: **Average Efficiency and Total Throughput**

	CCR	**BBC**	**Mean**	**Rank by Total Throughput**
Lázaro Cardenas	0.87	0.9	0.885	3
Manzanillo	0.88	0.88	0.88	1
Veracruz	0.29	0.74	0.515	2
Altamira	0.49	0.52	0.505	4
Ensenada	0.27	0.48	0.375	6
Progreso	0.23	0.35	0.29	5

Fourth conclusion is that exist a positive relation between traffic throughput, geographical location and efficiency. This statement is based on the results obtained which suggest that hub ports as the most efficient ports and therefore they tend to attract more cargo.

Finally, the study will suggest that Hub ports not just enjoy the benefits of economies of scale but also hub ports operate relatively more efficient than secondary ports. In addition, hub ports are strategically located covering broader areas of influence through their hinterland network connectivity. Furthermore, Carlos Martner (2002) affirms that smaller ports will have to find their own market niches and areas of specialization; if not, they are likely to end up excluded from international transport networks.

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Appendices

1) Weight of virtual DMUs based on DEA CCR

DMU	Score	V(1) L_Berth	V(2) Stg_a	V(3) Cranes	U(1) Tons	U(2) TEU
2002A	0.416411	4.34E-04	0	8.55E-02	0	0
2002E	0.324887	0	1.20E-05	0.334656	0	0
2002L	0.712284	2.82E-04	0	3.78E-02	0	0
2002M	0.723715	8.03E-04	0	0.026731	0	0

2002P	0.227825	1.30E-03	0	0.174827	0	0
2002V	0.523867	0	0	4.80E-02	0	0
2003A	0.391283	4.17E-04	0	8.22E-02	0	0
2003E	0.330608	0	0	0.270125	0	0
2003L	0.774829	2.59E-04	0	3.48E-02	0	0
2003M	0.751816	7.73E-04	0	2.57E-02	0	0
2003P	0.25702	1.14E-03	0	0.153246	0	0
2003V	0.488391	0	0	4.57E-02	0	0
2004A	0.428335	3.69E-04	0	7.28E-02	0	0
2004E	0.371635	0	0	0.240305	0	0
2004L	0.726908	2.92E-04	0	3.92E-02	0	0
2004M	0.854339	7.08E-04	0	2.36E-02	0	0
2004P	0.256532	1.14E-03	0	0.153538	0	0
2004V	0.229065	2.64E-04	0	3.55E-02	0	0
2005A	0.455011	3.37E-04	0	0.06644	0	0
2005E	0.278281	0	0	0.221855	0	0
2005L	0.843196	2.38E-04	0	3.20E-02	0	0
2005M	1	6.43E-04	0	2.14E-02	0	0
2005P	0.2876	1.02E-03	0	0.136952	0	0
2005V	0.21029	0	0	3.98E-02	0	0
2006A	0.48636	2.97E-04	0	5.86E-02	0	0
2006E	0.299491	0	0	0.194156	0	0
2006L	1	2.25E-04	0	0.030196	0	0
2006M	0.930704	4.60E-05	0	2.67E-02	0	0
2006P	0.302344	1.01E-03	0	0.135615	0	0
2006V	0.219645	2.29E-04	0	0.030755	0	0
2007A	0.601765	2.55E-04	0	5.02E-02	0	0
2007E	0.285449	0	0	0.230986	0	0
2007L	0.9366	2.00E-04	0	3.95E-02	0	0
2007M	1	1.39E-03	0	0	0	0
2007P	0.206331	0	0	0.307914	0	0
2007V	0.202164	2.47E-04	0	3.32E-02	0	0
2008A	0.60702	2.38E-04	0	4.70E-02	0	0
2008E	0.181625	0	0	0.363026	0	0
2008L	0.93448	1.87E-04	0	3.68E-02	0	0
2008M	1	1.39E-03	0	0	0	0
2008P	0.16203	1.53E-03	0	0.302072	0	0
2008V	0.211452	2.37E-04	0	3.17E-02	0	0
2009A	0.519347	2.78E-04	0	0.054891	0	0

2009E	0.121602	0	1.82E-05	0.507704	0	0
2009L	1	1.75E-04	0	3.44E-02	0	0
2009M	0.818479	1.69E-03	0	0	0	0
2009P	0.113589	0	0	0.6508	0	1.87E-05
2009V	0.196746	2.54E-04	0	3.41E-02	0	0

2) Weight of virtual DMUs based on DEA BBC

DMU	Score	V(0)	V(1) L_Berth	V(2) Stg_a	V(3) Cranes	U(1) Tons	U(2) TEU
2002A	0.416735	-2.10447	7.56E-04	0	0.168954	0	0
2002E	1	-3.181567	0	1.59E-05	0.460768	0	0
2002L	0.774384	1.146171	0	0	9.68E-03	0	0
2002M	0.723715	0	8.03E-04	0	0.026731	0	0
2002P	0.331892	-6.53812	2.69E-03	0	0.396439	0	0
2002V	0.714527	1.124225	0	0	9.49E-03	0	0
2003A	0.402607	0.714926	3.10E-04	0	5.43E-02	0	0

2003E	0.644729	-2.568076	0	1.28E-05	0.37192	0	0
2003L	0.842382	1.053651	0	0	8.90E-03	0	0
2003M	0.751816	0	7.73E-04	0	2.57E-02	0	0
2003P	0.370585	-5.731048	2.35E-03	0	0.347503	0	0
2003V	0.726235	1.069816	0	0	9.03E-03	0	0
2004A	0.444526	0.633657	2.74E-04	0	4.81E-02	0	0
2004E	0.724736	-2.284575	0	1.14E-05	0.330862	0	0
2004L	0.759078	1.187076	0	0	1.00E-02	0	0
2004M	0.854339	0	7.08E-04	0	2.36E-02	0	0
2004P	0.36988	-5.741965	2.36E-03	0	0.348165	0	0
2004V	0.690869	1.447453	0	0	0	0	0
2005A	0.482082	1.683118	0	0	1.86E-02	0	0
2005E	0.356994	-2.109169	0	1.05E-05	0.305459	0	0
2005L	0.916709	0.96822	0	0	8.18E-03	0	0
2005M	1	0	6.43E-04	0	2.14E-02	0	0
2005P	0.414677	-5.121679	2.10E-03	0	0.310553	0	0
2005V	0.741337	1.348914	0	0	0	0	0
2006A	0.54224	1.544276	0	0	1.30E-02	0	0
2006E	0.367815	-1.845837	0	0	0.267322	0	0
2006L	1	0	2.25E-04	0	0.030196	0	0
2006M	0.930704	0	0	0	2.67E-02	0	0
2006P	0.480664	-5.071686	2.08E-03	0	0.307522	0	0
2006V	0.797067	1.254599	0	0	0	0	0
2007A	0.641663	1.264528	0	0	1.40E-02	0	0
2007E	0.364352	-2.066576	0	1.03E-05	0.299291	0	0
2007L	0.939738	0.93936	0	0	1.04E-02	0	0
2007M	1	0	1.39E-03	0	0	0	0
2007P	0.398169	-8.692112	3.57E-03	0	0.527047	0	0
2007V	0.738585	1.353941	0	0	0	0	0
2008A	0.675961	1.238782	0	0	1.05E-02	0	0
2008E	0.230389	-3.268217	0	1.63E-05	0.473318	0	0
2008L	0.940113	0.920988	0	0	1.02E-02	0	0
2008M	1	0	1.39E-03	0	0	0	0
2008P	0.248196	-9.821983	4.03E-03	0	0.595557	0	0
2008V	0.772519	1.294466	0	0	0	0	0
2009A	0.5745	1.387439	0	0	1.54E-02	0	0
2009E	0.155998	-4.82673	0	2.41E-05	0.699028	0	0
2009L	1	0	1.75E-04	0	3.44E-02	0	0
2009M	0.818479	0	1.69E-03	0	0	0	0

2009P	0.172026	-10.36733	3.73E-03	0	0.832322	0	0
2009V	0.718791	1.391225	0	0	0	0	0