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Data Envelopment Analysis of the Efficiency of Container Ports in Sagarmala Programme

by

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Summary

The coastal areas are the main economic activity centers for many nations, especially the developing countries. The biggest contributor for these activities are the ports located in the coastal areas, since they generate significant growth and development for the communities. Hence it is vital to improve the performance of these economic centers not only for the communities, but also to cater to the increasing global sea trade. The ports in India are not different to the impact of the rise in global container trade as indicated by the trends of total exports and imports when compared to the container throughput in the last decade. The Government of India identified the need for improving the performance of the ports along with overall port-led development and hence implemented the SagarMala programme in 2015. This research focuses on measuring the efficiencies of container terminals in India and identify the impact of SagarMala programme on the efficiencies.

The main research question that needs to be addressed is: **How do the state-owned ports in India perform with respect to efficiency parameters owing to increased competition from private ports?**

In addition to the main question, the following sub-questions are also required to be addressed to achieve the objectives of this study.

a) What are the port governance issues concerning state-owned ports in India with respect to the performance?
b) Why DEA methodology is more suitable to measure port efficiency? What are the standard inputs and outputs generally considered in DEA?
c) Which are the ideal container terminals that can be referred by inefficient terminals to improve the efficiencies?
d) What are the initiatives in the Sagarmala programme that can have positive effects on the efficiencies?

The container terminals, analysis methodology and corresponding input/output parameters are selected based on the literature review and the SagarMala programme. The analysis is carried out considering the non-parametric methodology called the data envelopment analysis (DEA). The main advantage of DEA method is that it does not impose any functional form a *priori* on the data and it handles multiple input-output processes.

All the container terminals in India that handle an annual throughput of 10,000 TEUs are considered for this research. A total of 27 container terminals are identified along the coast of India, among which 18 are in major ports and 9 are in minor ports. The western state of Gujarat has the higher number of terminals (7 numbers), and the west coast has slightly more number of terminals (15) compared to the east coast (12), owing to increased

economic activity. The study period considered for this study is from FY 2014-15 until FY 2020-21.

The input parameters considered for this study and their units are: quay length (m), terminal area (ha), number of quayside gantry cranes (nos.), number of yard gantry cranes (nos.). The output parameters are: throughput (TEU), revenue (INR). The data is collected from Indian Container Market Reports, Indian Ports Association and Gujarat Maritime Board.

The analysis is performed using the Data Envelopment Analysis (Computer) Program developed by Coelli (2007). The results are validated by using open-source data analysis software called R-Studio with “deaR” package.

The results indicated that the efficiencies of container terminals in major ports have reduced during the study period compared to the minor ports. However, the three most efficient container terminals are found to be in the major ports (viz., APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal). The efficiencies of port clusters in Maharashtra showed significant reduction, whereas the port clusters in Gujarat have shown increased efficiencies. The private ports are found to be more efficient in closer proximity, that increased the competition and hence the shift of efficiencies. It is also observed that the ports in the west coast are more efficient than their counterparts in the east coast.

The major ports are affected by the governance issues like fixing tariffs, rigid hierarchy, excess personnel, lack of executive power, authority, and excess bureaucracy. The SagarMala programme aimed to install additional quay and yard cranes, automate gates to reduce process time and bottlenecks. The programme aimed to develop the area surrounding the yard for easier access and exit to the trucks and trains, including investing in upgrading the railway yard. This will provide faster access of cargo to the hinterland and improve connectivity between the production hubs and the ports. The programme has an objective of improving hinterland connectivity by providing direct unhindered access to the Inland Container Depots (ICD) by rail and trucks. These initiatives might have influenced the performance of most efficient major ports. Other inefficient major ports can also assess the need for similar initiatives to improve their performance.

This research can be extended to include impact of major events like Covid-19 pandemic, Suez Canal blockage, and Yantian port congestion on Indian container terminals. Other types of cargo (break bulk and liquid bulk) can also be considered for future study and assess the impact of the SagarMala programme.

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1 Introduction

The subject matter of this thesis is to evaluate the strategic competitive positions of various state-owned ports under the Sagarmala programme from Government of India (GoI). The relative efficiencies of the container handling ports are measured and compared with those of major ports in India to analyze the competitive advantages and disadvantages. This thesis mainly focuses on measurement of the relative efficiencies through comparative analysis and comprehend the underlying strengths and weaknesses in respect of major port performance. This section will present a brief introduction and background of the research, along with the problem definition and objectives of the study. Furthermore, the research questions and sub-questions derived from the objectives are presented, in addition to a brief introduction of the research methodology and data collection. The section concludes with the thesis structure that describes the essence of each sections.

1.1 Research background

The rise and fall of world economy and trade directly impacts the shipping due to its derived demand. This is also the main reason for reduced growth in shipping since almost two years, firstly due to the trade tensions between the major economies and then due to the Covid-19 pandemic. Hence the international maritime trade slowed down with the global GDP in 2020. (UNCTAD, 2020b)

It is seen in most countries, especially the developing countries, that the major economic activities are concentrated along the coastal areas. This is due to the ports located in the coastal areas create wide varieties of commercial activities and benefit the economy. The ports include many economic activities such as cargo loading/unloading, cargo storage, logistics, hinterland transport etc. The activities include many stakeholders and generate substantial jobs and development for the communities. (Dwarakish & Salim, 2015). However, it is also important for the countries to continuously improve the quality of port infrastructure and the services offered, especially in logistics. This will lead to an increase in the seaborne trade catered by the port and subsequently the economic growth (Munim & Schramm, 2018).

As per UNCTAD data, India constitutes just over one percent of the global share of coastline with over 7500 km extending from east to west (UNCTAD, 2020a). Naturally, around 90% of EXIM cargo by volume and 70% by value is handled by 12 major ports and 200 non-major ports in the country. The major and minor container ports in India are spread across the coastline with almost equal numbers on west and east coasts, as shown in Figure 1.

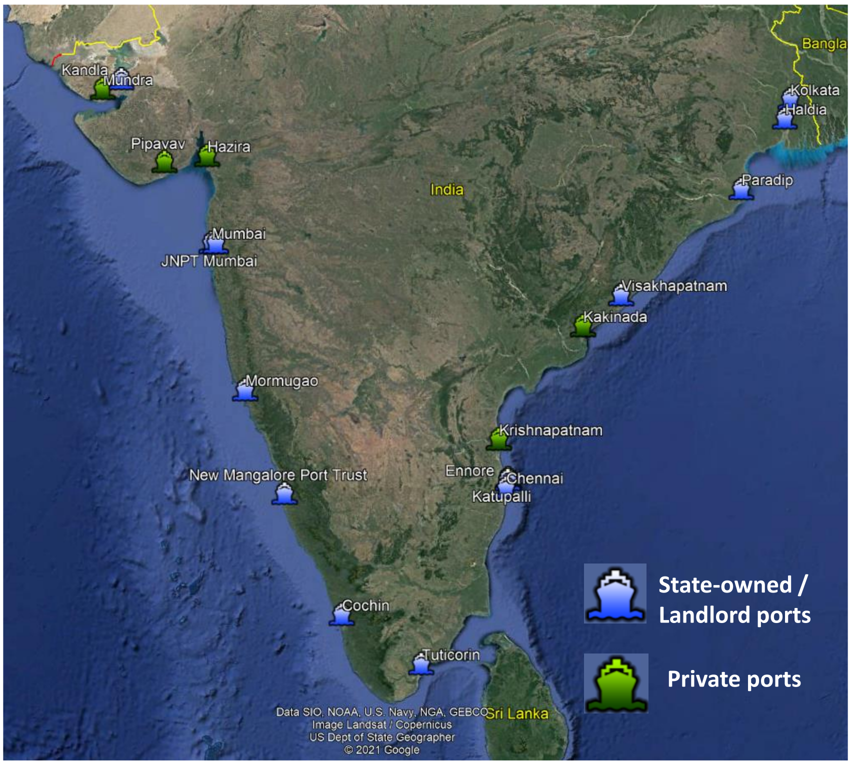


Figure 1: Key container ports in India
(Source: Own illustration based on (Iyer & Nanyam, 2021)

The growth of container throughput (in TEU) in the last 10 years reflects the exports and imports traded with India as shown in Figure 2. This indicates the importance of maritime trade in India and consequently the associated ports and port cluster development.

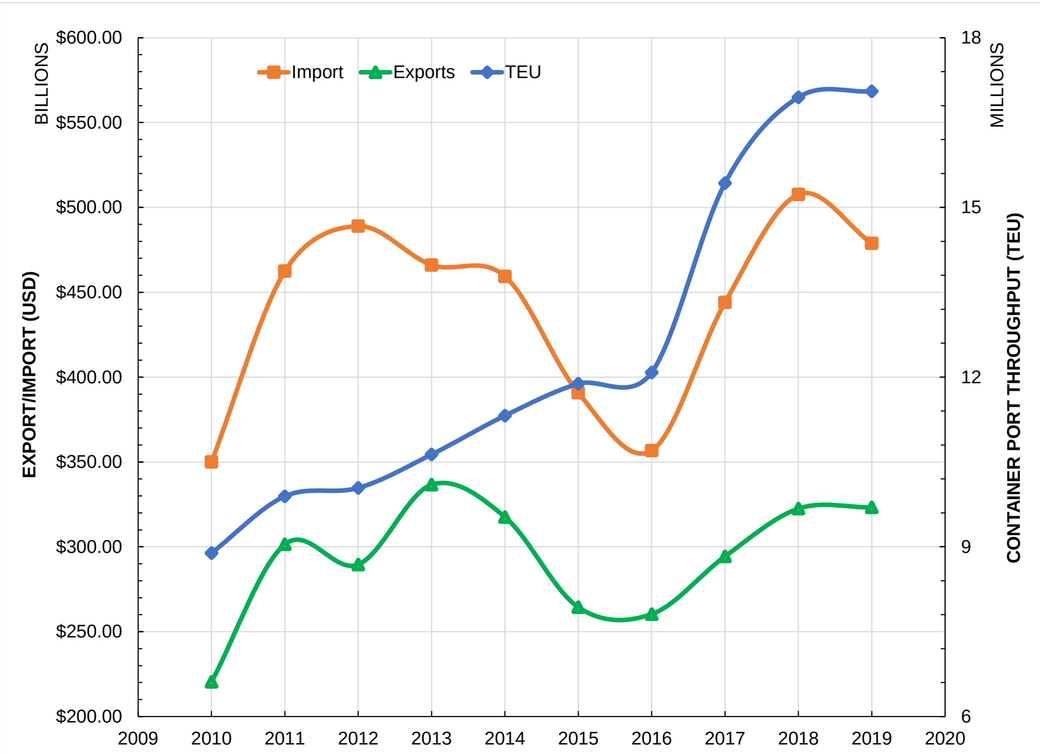


Figure 2: India container throughput (TEU) and EXIM value (USD) from 2010 to 2019.
(Source: Own illustration based on (UNCTAD, 2020a))

Most of the ports in India are situated close to key international trade routes. In addition to the 7,500 km long coastline, India also has 14,500 km of potentially navigable inland waterways. The GoI identified the need for comprehensive development of the coastline and waterways, thereby reducing the logistics cost on EXIM and domestic trade. Hence the concept of Sagarmala was introduced and approved by the Union Cabinet on 25th March 2015 with the main mission of "port-led development" (Ministry of Ports, 2019). The port-led development would essentially encompass overall development focused on ports, logistics (hinterland transport), associated industries, and coastal communities. The activities form the main pillars of Sagarmala programme and are primary development objectives of GoI, as shown in Figure 3.

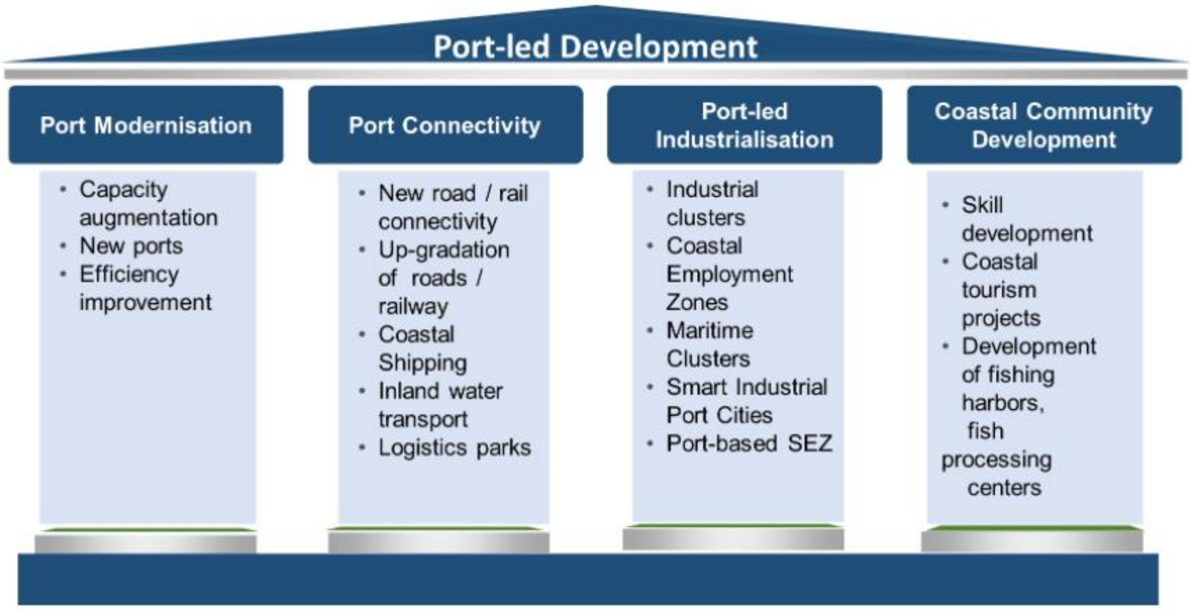


Figure 3: Four pillars of Sagarmala programme
(Source: (Ministry of Ports, 2019))

Due to the numerous complex processes involved in a port, it is not viable to study them as a single (homogenous) entity. Hence it is important to identify common variables between different ports to measure the port efficiencies. The port management perspective to evaluate the port efficiencies can be categorized based on strategic, economic and operational perspective. Each perspective involves different criteria for evaluation as shown in Figure 4 (Mahfouz & Arisha, 2009). Therefore, the efficiencies of different ports can be measured and compared by considering suitable perspectives and corresponding approaches or terms.

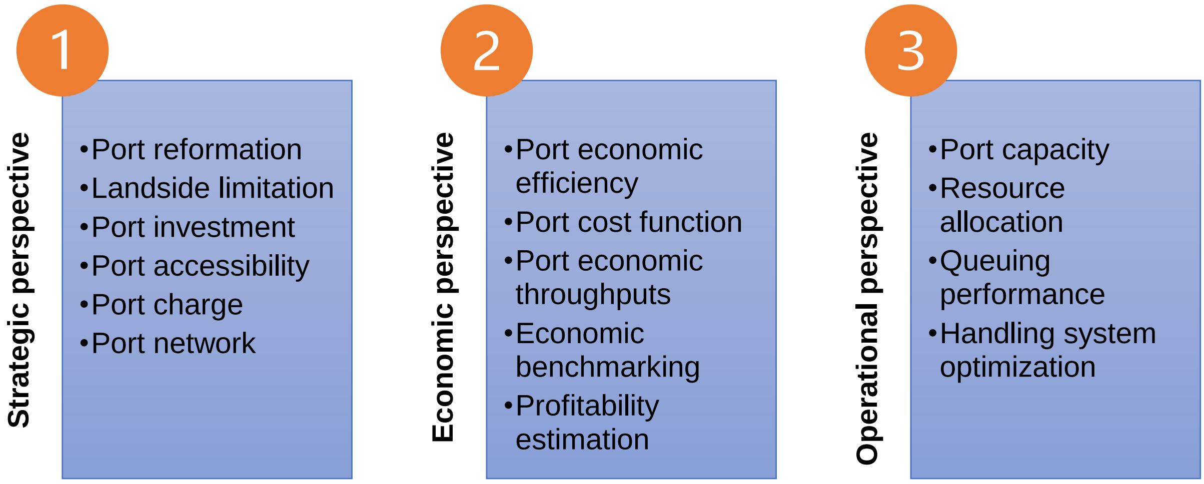


Figure 4: Classification of port management perspectives
(Source: Own illustration based on (Mahfouz & Arisha, 2009))

1.2 Problem definition

The ports around the world are benefitting from the economies of scale by introducing advanced technologies and strategies to increase the productivity and the efficiency. However, this is not evident in most of the Indian ports, especially in state-owned ports. Iyer & Nanyam (2021) concluded that even the major ports that handle throughput exceeding 1 Million TEU per year have showed reduced efficiency compared to minor ports. Very few studies have been conducted to evaluate the efficiencies of Indian ports, especially compared to private ports. In the current global scenario, often ports in the same region are found to have similar efficiencies (for eg., Singapore & Hong Kong in Asia, Rotterdam & Antwerp in Europe) (MONTEIRO, 2018). Hence it is important to assess the efficiencies of Indian ports, reasons for reduced efficiencies (if any) and scope for improvement. This will also help in understanding the progress of Indian ports over the years to accommodate increasing vessel sizes and improve infrastructure for better hinterland connectivity (Iyer & Nanyam, 2021). Evaluating the efficiencies of ports connected by Sagarmala programme will also help in assessing the influence of the programme and achievement of its objectives so far.

It is also noted in Iyer & Nanyam (2021) that most of the studies on efficiency of Indian ports consider berth (quay) length, total quayside cranes and total yard equipment as the main inputs. Some researchers have also considered the terminal area as an input. However, total throughput is agreed as the most common output variable by all researchers. With increase in competition from private ports, it is pertinent for state-owned ports to improve efficiencies and increase market share.

1.3 Aim of the study

This study focuses on the comparative analysis to measure the efficiencies of state-owned (public service) ports that are part of Sagarmala programme. The study aims to compare the efficiencies of state-owned ports with private ports using similar variables in economic and operation perspectives. The ports on both east and west coast of India are considered for this study. The assessment is carried out using Data Envelopment Analysis(DEA) technique, a non-parametric method. This technique uses similar variables between different entities, compares the technical efficiencies and ranks them based on their performances. The study also aims to identify governance issues that impact the port efficiencies and influence the overall performance of the state-owned ports.

1.4 Research questions

This research is carried out in different stages to achieve the desired objectives. Firstly, the key major and minor ports are identified among all the state-owned and private container ports in India. Secondly, the performance parameters under economic and operation perspectives are identified that are common for all the selected ports. The performance parameters form the input and output variables for the DEA technique. Thirdly, the DEA technique and applicability of various DEA models are evaluated and suitable models are selected. Lastly, the key strategies and governance criteria that affect the competitiveness between state-owned and private ports are discussed.

The main contribution of this study is its aim to expand the limited existing knowledge on applicability of DEA technique to measure efficiencies of state-owned and private ports in India and analyze the impact of governance on performance.

Therefore, the main research question that needs to be addressed is: **How do the state-owned ports in India perform with respect to efficiency parameters owing to increased competition from private ports?**

In addition to the main question, the following sub-questions are also required to be addressed to achieve the objectives of this study.

a) What are the port governance issues concerning state-owned ports in India with respect to the performance?

b) Why DEA methodology is more suitable to measure port efficiency? What are the standard inputs and outputs generally considered in DEA?

c) Which are the ideal container terminals that can be referred by inefficient terminals to improve the efficiencies?

d) What are the initiatives in the Sagarmala programme that can have positive effects on the efficiencies?

1.5 Data and methodology

1.5.1 Data collection

This study mainly focuses on non-parametric analysis using primary data. The data required for this quantitative analysis are mainly the performance parameters with respect to economic and operation perspectives. The input parameters are the resources required for a container terminal operation and include the quay length (m), terminal area (ha), quayside gantry cranes (numbers) and yard gantry cranes (numbers). The input data are collected from the Indian Container Market Reports and websites of the port operators. The output parameters considered are the container throughput (TEU) and annual revenues (INR). The output parameters are also collected from the Indian Container Market Reports and verified with corresponding data from Indian Ports Association. The detailed description of data collection and respective sources are presented in Section 3.2 and 3.3.

1.5.2 Methodology

The methodology adopted in this study is selected after comparison of two main methods of efficiency measurement: data envelopment analysis (non-parametric method) and stochastic frontier analysis (parametric method). Due to the main advantage of handling multiple inputs and outputs, the data envelopment analysis is selected for this study. In the DEA method the efficiency of a firm (called decision making unit) is measured by comparing with homogenous units that use the same resources for production of same outputs. The two main (classic) models of DEA are CCR and BCC models, named after their authors. The CCR model assumes constant returns to scale, which means the production of outputs change in the same proportion as the changes in the inputs. Meanwhile, the BCC model assumes variable returns to scale.

The container terminals and methodology are selected based on the literature review carried out in Section 2. Then the analysis is carried out using the collected data to obtain efficiencies, slacks and references of the container terminals. The slacks indicate the level of utilization of the resources (inputs), whereas the references (peers) indicate similar terminals which can be referred by inefficient terminals to improve their efficiencies.

Subsequently, the results obtained from the analysis are interpreted and correlated with the development initiatives implemented in the SagarMala programme.

1.6 Thesis structure

In view of the above problem definition, research objectives and methodology, the report is structured into following sections (chapters).

Section 1 – Introduction: This section discusses the research background on economic importance of Indian ports and need for assessment of their efficiency. The underlying research problem is identified that leads to the objectives of the research and consequently to the research questions and sub-questions. Finally, the sources of data used in the research are introduced along with the research methodology.

Section 2 – Literature review: This section presents an extensive review of academic literature on container ports in India and the challenges encountered in operations and administration in terms of policies, regulations and governance. Furthermore, the measurement of efficiencies of container ports is also studied with particular attention to DEA technique.

Section 3 – Methodology: The various methods adopted to evaluate efficiencies of container ports are reviewed based on academic literature and the reason for selection of DEA is presented in this section. The input and output variables used for the analysis and other datasets are also described here. The section is concluded with a description of application of DEA and assumptions made in the analysis, if any.

Section 4 – Research findings and interpretations: The results obtained from the analysis carried out in the previous section are summarized and interpreted in this section. The efficiencies of the container ports obtained are also explained to identify the fundamental issues concerning port governance.

Section 5 – Conclusion: This section presents the final conclusions from the analysis using DEA technique and subsequent results and discussions described in the previous sections. Eventually the answers for research question and sub-questions will also be described based on the research findings. This section concludes by presenting the limitations of the research and recommendations for future research.

2 Literature review

2.1 Introduction

The academic literature that form the background of this research are presented in this section. The literature review will focus on studies carried out on container ports in India and their governance (management) models. Subsequently, the literature on efficiency of container ports, especially using data envelopment analysis will be presented. The section ends with the discussion on the literature review and excerpts applicable to the present study.

2.2 Overview of Indian container ports

The size of vessels and type of shipping for any trade are physically constrained by the ports, especially in terms of cargo handling rates and berth utilization, affecting the profitability of vessels. Hence the shipping operations are increasingly dependent on the port effectiveness, capacity and technology (Frankel, 1997). The entire port sector and shipping in India, including conservation, regulation and administration are governed as per the rules laid down in the Indian Ports Act (1908). Whereas the institutional framework for the 12 major ports in India are laid down in the Major Port Trust Act (1963) (Ray, 2004).

Subsequently, the reformation brought in India by the de-regularization in the early 1990s has significantly improved the performances of Indian ports and the national economy. Until the late 1990s “Indian ports are characterized by the existence of obsolete and poorly maintained equipment, hierarchical and bureaucratic management structures, excessive labour and, in general, an institutional framework that is considerably in variance with the Government's overall economic objectives” (Haralambides & Behrens, 2000). Haralambides & Behrens (2000) also highlighted the “significant need for port modernization and coordinated port development”. The container shipments in Indian ports accounted for nearly 22 percent of total export cargo volume in 2007 and had increased by nearly 14 percent by the end of the year to 5 million TEUs (Ng & Gujar, 2009).

However, Indian ports are often found to be least competitive owing to inadequate infrastructure coupled with institutional and procedural delays, that have resulted in inefficient operations (Ghosh & De, 2001). Moreover, De (2009) also highlighted that the port charges in India are extremely high compared to their counterparts in other Asian countries. Sinha & Bagodi (2019) measured the key performance parameters between JNPT, India’s largest container handling port, with the port of Shanghai. They found that JNPT handled 4.4 million TEU in 2017-18, whereas Shanghai handled 40 million TEU during the same period. Also they observed that the productivity (moves per hour) reduced in JNPT from 2017 to 2018, whereas dwell time increased.

As per Drewry (2019) report, there are 28 main container terminals (yearly throughput > 10,000 TEU) under operation in India. The administrative classification and location (east or west coast) of the terminals are shown in the figure below.

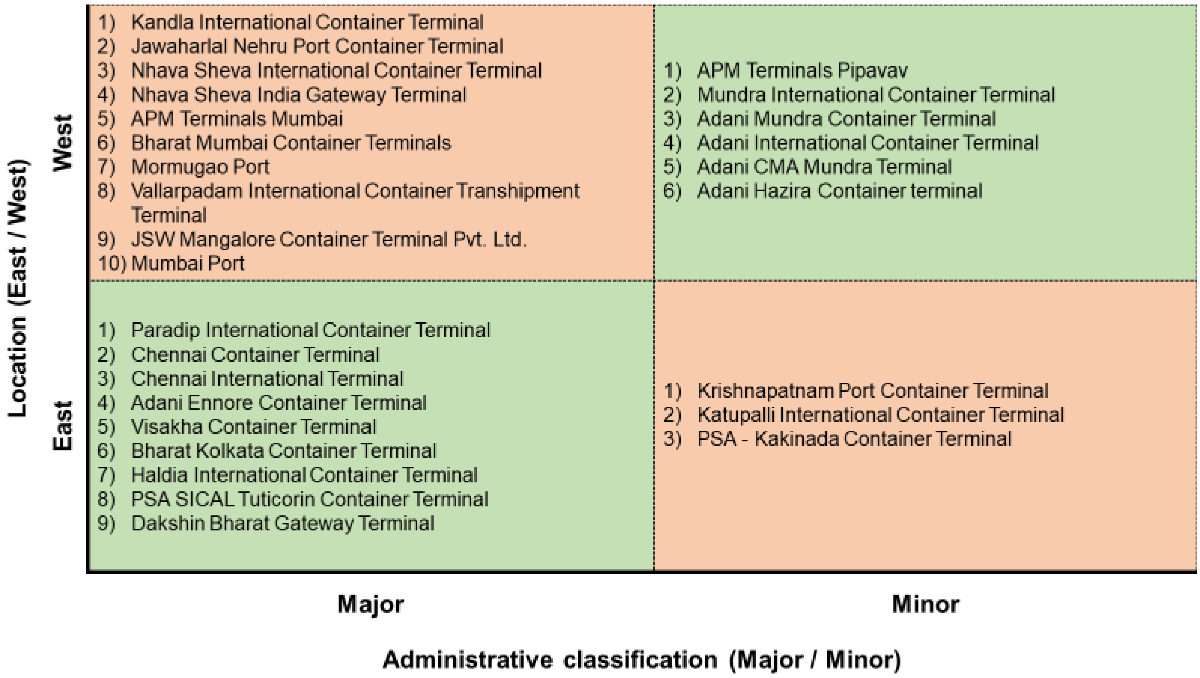


Figure 5: Administrative classification and location of Indian container terminals
(Source: Own illustration based on (Drewry & Maritime Gateway, 2019))

Drewry (2020) also reported the impact of Covid-19 on Indian container ports, their throughputs and YOY growth for fiscal year 2019-2020. The Indian container terminals were categorized based on their throughput and YOY growth as follows:

	Throughput (TEU)	YOY Growth (%)
High	> 700,000	> 12%
Moderate	700,000 – 350,000	6% – 12%
Low	< 350,000	< 6%

As per the Drewry report(2020), Adani CMA Mundra Terminal, Bharat Mumbai Container Terminals, Mundra International Container Terminal showed high throughput and high growth. On the other hand, Haldia International Container Terminal, Kakinada Container Terminal and Tuticorin Container Terminal showed low throughput and low growth. India's largest container terminal, JNPCT showed high throughput but low growth.

The pricing mechanism greatly affects the efficiencies of Indian ports. Since a ship pays for number of days it stays in the berth, ports earn more on account of inefficiencies since ships stays longer in such ports. Moreover, the ports' inability to take proactive actions especially with regards to capacity enhancement and infrastructure development add to the inefficiencies, owing to long gestation periods of port projects. (Sinha & Bagodi, 2019).

Hence there is a need for improvement in port governance and reforms considering port as a commercial activity without affecting the social benefits.

2.3 Port governance and reforms

The port competitiveness and efficiency is always believed to improve by private sector participation in the industry, especially owing to adaptability to customer's demand, which will in-turn guide the port authorities and operators to formulate strategies for efficiency and competitiveness (Tongzon et al., 2005). It is also debatable if the privatization is part of government devolution programs, since there are arguments over applicability of decentralization, commercialization, corporatization and privatization in port sector. Rodal & Mulder (1993) define devolution as "the transfer of functions or responsibility for the delivery of programs and services from the federal government to another entity". But, Brooks (2004) argues that the extent of devolution may range from partial to full privatization.

The definition of governance is broadly described in the World Bank Policy Research Working Paper (2007) as "the traditions and institutions by which authority in a country is exercised. This includes the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them." Hence Brooks & Cullinane (2007) emphasize that "the systems, structures and processes that organize groups of individuals to a common purpose can be perceived as constituting the governance structure of the group".

However, it is understood that we cannot expect the corporations to deliver the same social welfares or public policy objectives that the governments provide. The port governance models based on port functions and their responsibilities under port management models are defined in The World Bank Port Reform Toolkit (2007) as shown in the table below.

Table 1: Basic port management models

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

(Source: (World Bank, 2007))

The landlord model is found to yield maximum economic surplus on an aggregate level for both port authority and port users (Munim et al., 2019), whereas port reform and governance studies indicated private sector participation and port corporatization leads to increased operational efficiency ((K Cullinane & Song, 2003) & (K Cullinane, 2010)). The public sector ports often find it difficult to provide the user experience that is expected of them, especially in the longer term. During such scenarios, it is imperative to include private sector management to achieve the required objectives (Asian Development Bank., 2000).

The Indian ports are classified as major and minor based on strategic and administrative significance laid out in the Major Port Trusts Act (1963) that defined the word “major ports” for twelve ports and suggested creation of separate port authorities, which were under the direct administrative control of the central or state government until then (i-maritime, 2003). The institutional framework of Indian ports sector can be explained as shown in the figure below.

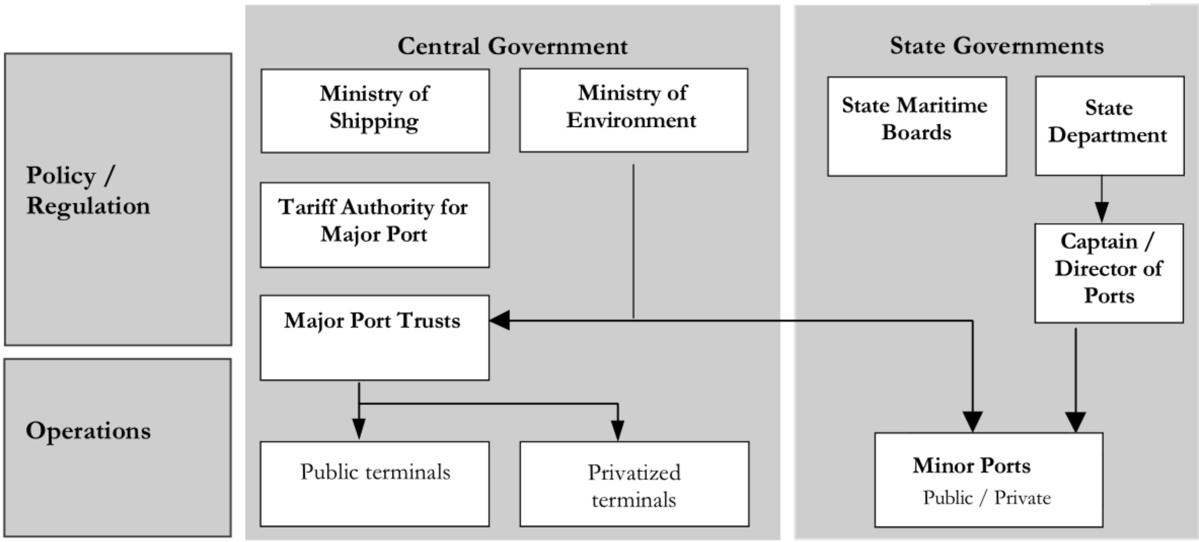


Figure 6: Institutional framework of Indian port sector
(Source: (i-maritime, 2003))

The salient features and limitations of the Major Port Trusts Act (1963) are listed in the Table 2. The major ports in India are mostly controlled by the government through the Shipping Corporation of India, whereas minor ports are mostly private controlled. The Indian government has provided support to the maritime development by “reshaping policies to foster greater competition among ports”, “creating entrepreneurial opportunities for private entities in order to reduce fiscal burden and increase commercial activity”, and “planning and delivering major inland infrastructure for better hinterland connectivity and market access” (Subramanian & Thill, 2019).

de Langen (2020) agrees that there is no ‘one size fits all’ governance model, although there are clear indications for appropriate and specific governance models for specific contexts. This largely involves considering port operation as a commercial activity, which is clearly missing in Indian ports notably in major ports.

Table 2: Salient features and limitations of the Major Port Trusts Act

SALIENT FEATURES	LIMITATIONS
➢ Independent and autonomous board of trustees. ➢ Transfer ownership and control of all port assets and liabilities. ➢ Power and authority to raise, borrow or invest resources. ➢ Tariff Authority for Major Ports (TAMP) to fix port related tariffs (Amendment 1997)	➢ Political pressures. ➢ Rigid hierarchy. ➢ Excess of personnel. ➢ Lack of autonomy. ➢ Lack of incentives. ➢ Lack of commercial orientation. ➢ Excess of bureaucracy.

(Source: (i-maritime, 2003))

The port reforms in India essentially include policy, organizational, capacity, and regulatory issues. The key issues pertain to different areas of port development as shown in the figure below.

Policy issues	Organizational issues	Capacity issues	Regulatory issues
• Private sector partiticipation (PSP) • Corporatorization • Competition • Connectivity	• Labor • Equipment • Management (coordination)	• Capacity augmentation • Creation of new facilities & ports • Feasibility of hub ports	• Safety and conservancy • Environmental • Economic (tariffs and entry)

Figure 7: Key issues involved in port reforms in India
(Source: Own illustration based on (Ray, 2004))

The i-maritime report (2003) also highlights the need for port regulatory reforms for the following reasons:

a) Improving efficiency and reducing costs
b) Changing nature of port operations (automation)
c) Need for leveraging private sector investment
d) Changing role of Government / port authority

However, the port authority alone cannot provide the required benefits in terms of education and training, marketing and promotion, information exchange, societal license and congestion reduction, especially in a landlord business model. A collective action is required from all the stakeholders to strengthen the port cluster performance.(de Langen, 2020)

2.4 Efficiency of container terminals

Most ports are recognized as producers of multiple outputs, liquid bulk, dry bulk, containerized cargo, break bulk, ro-ro, etc. Nevertheless, it is common to limit the efficiency measurement to container terminals (Løvold et al., 2015). It is evident from the literature review that only the economic performance is considered as an important criteria ignoring other equally important factors like social, environmental and political performances. The economic performance of a port is often measured using two main concepts: productivity and efficiency. The productivity is defined as the ratio of the output volume to the input volume. Whereas efficiency deals with the production of maximum output with given inputs and is a relative concept compared against a benchmark (Liu, 2010).

One of the earliest studies on measurement of efficiencies of ports were reported by Roll and Hayuth (1993) using the data envelopment analysis to evaluate the efficiency of 20 ports. Many researchers have successfully reported various methods for measurement of operational efficiency since the first study was carried out (Løvold et al., 2015). It is however concerning that the relationship between efficiency and corresponding operating / organizational conditions shows a great degree of discrepancy across many researchers. This is particularly seen when the scale of port, type of ownership and impact of port reforms are considered as the main contributors for port efficiency. (Bichou, 2013)

Kevin Cullinane et al., (2002) used the stochastic frontier model to measure the efficiencies of major container terminals in Asia. They concluded that the economic efficiency of ports is closely correlated with the size of the port and improves with the ownership transformation from a public to a private port. In contrast Notteboom et al., (2000) used the same stochastic frontier model on 36 European container terminals and four Asian container terminals and found that ownership type (public or private) have minimal impact on the efficiency, which is more dependent on type of port operations (hubs or feeders). Wang et al., (2005) observed that the economic efficiency of container terminals vary with the scale of the port whereas Bonilla et al., (2002) showed contradicting views. The economic efficiency with regards to the port reforms also indicating wide variation in many studies. Gonzaíez & Trujillo (2009) showed that port reforms have significant impact on efficiencies of ports, whereas Coto-Millan et al., (2010) argue that the "combination of decentralization and deregulation would have a negative influence on port efficiency".

The contrasting results raise questions on the methodology adopted to measure economic efficiencies. It is observed that the majority of studies of economic efficiencies are carried out for ports in European countries. This might be due to the availability of data from ports and also because of political issues, security situation and lack transparency in other countries. It is however agreed across the academic spectrum that the empirical estimations of efficiencies depend significantly on the methodology used, type of data and region/country where the ports are located (Odeck & Bråthen, 2012).

Irrespective of numerous studies conducted on efficiency measurement of container terminals, few studies focus on benchmarking results to port market and operating conditions namely production scale, cargo mix, transshipment ratio, operating configurations and working procedures. Bichou (2013) formulated many operational hypotheses to test the sensitivity of efficiencies for 420 container terminal decision making units (DMU). They showed that terminals with high proportion of transshipment, FEU and/or empty containers yield higher efficiency. The use of automated systems and procedures that decide the yard storage and gate operations also impact the efficiencies significantly.

Therefore, the literature review suggests that the efficiencies of container terminals depend on various operating parameters and the methodology considered, along with the geographical location and type of ownership. It is imperative to arrive at a suitable methodology and consider the operating parameters that is common for all the DMUs adopted.

2.5 Data envelopment analysis (DEA)

The literature review suggests the two most popular methods of efficiency measurement: data envelopment analysis (non-parametric method) and stochastic frontier analysis (parametric method).

The main advantage of DEA method is that it does not impose any functional form a *priori* on the data and it handles multiple output processes. Also, it is less sensitive to errors resulting from bad functional specifications. Gonzaíez & Trujillo (2009) highlighted the main differences in characteristics of DEA and stochastic frontier analyses as shown in Figure 8.

DEA is defined as a non-parametric method of measuring the efficiency of a firm with multiple inputs and/or multiple outputs. In this method a single “virtual” output is constructed to a single “virtual” input without pre-defining a production function. The term DEA and its first model (CCR) were coined by the authors Charnes, Cooper and Rhodes based on their paper titled “Measuring the efficiency of decision making units” (1978). DEA measures efficiency of a firm (unit of assessment or decision making unit) by comparing it with other homogenous units that use the same inputs to produce same outputs.(Wang et al., 2005)

DEA	Stochastic frontier
• Non-parametric approach	• Parametric approach
• Deterministic approach	• Stochastic approach
• Does not consider random noise	• Considers random noise
• Does not allow statistical hypothesis to be contrasted	• Allows statistical hypothesis to be contrasted
• Does not carry out assumptions on the distribution of the inefficiency term	• Carries out assumptions on the distribution of the inefficiency term
• Does not include error term	• Includes a compound error term: one of one side and the other symmetrical (two queues)
• Does not require specifying a functional form	• Requires specifying a functional form
• Sensitive to the number of variables, measurement errors and outliers	• Can confuse inefficiency with a bad specification of the model
• Estimation method: mathematical programming	• Estimation method: econometric

Figure 8: Characteristics of DEA and stochastic frontier analysis
(Source: (Gonzaíez & Trujillo, 2009))

Wang et al., (2005) described the objective function of the fractional programming (FP) problem that is solved in CCR model to measure the maximum efficiency as follows:

$$(\mathrm{FP}_k) \quad \text{Max} \qquad U_k = \frac{\sum_{n=1}^{N} a_n y_{nk}}{\sum_{m=1}^{M} b_m x_{mk}}$$

$$\text{Subject to:} \quad \frac{\sum_{n=1}^{N} a_n y_{nk}}{\sum_{m=1}^{M} b_m x_{mk}} \leq 1 \quad (k = 1, 2, \ldots, K)$$

$$a_n \geq 0 \quad (n = 1, 2, \ldots, N)$$

$$b_m \geq 0 \quad (m = 1, 2, \ldots, M)$$

Where, $a_1, a_2, \ldots, a_N$ = input weights

$b_1, b_2, \ldots, b_M$ = output weights

x_{mk} = m^{th} input data of firm k

y_{nk} = n^{th} output of firm k

The first constraint indicates that the ratio of 'virtual output' to 'virtual input' cannot exceed 1 for each firm. In other words, it conforms to the economic assumption that the output cannot be more than input (Wang et al., 2005).

The fractional programming problem can also be formulated as a linear programming problem with the following equations.

$$(\text{LP}_k) \quad \text{Max} \qquad U_k = \sum_{n=1}^{N} a_n y_{nk}$$

Subject to:

$$\sum_{m=1}^{M} b_m x_{mk} = 1$$

$$\sum_{n=1}^{N} a_n y_{nk} \le \sum_{m=1}^{M} b_m x_{mk} \quad (k = 1, 2, \ldots, K)$$

$$a_n \ge 0 \quad (n = 1, 2, \ldots, N)$$

$$b_m \ge 0 \quad (m = 1, 2, \ldots, M)$$

There are two other DEA models that are widely studied and applied to measure efficiencies of DMUs: BCC model (Banker et al., 1984) and Additive model. The models are applied where variable returns-to-scale are assumed, whereas the CCR model allows constant returns-to-scale. Nevertheless, the basic information derived from the three different models is “whether or not a firm can improve its performance relative to the set of firms to which it is being compared” (Wang et al., 2005). The main drawback of DEA method is the use of ‘virtual’ output and inputs and their weighted sums, as highlighted by Farrell (1957) who provided the comprehensive framework for analyzing efficiency across firms, based on which the DEA method is developed. However, DEA method and notably CCR and BCC models are the most used non-parametric methods of measuring economic efficiencies of firms (Gonzaíez & Trujillo, 2009).

The CCR ratio model provides objective estimation of overall efficiency along with identifying the source of inefficiencies and their values. On the other hand, the BCC model differentiates “between the technical and scale efficiencies by estimating the pure technical efficiency at the given scale of operation” (Abraham Charnes et al., 1994).

Kevin Cullinane et al., (2004) indicated the need for input and output variables to reflect the actual objectives and process of the container terminal production as accurately as possible. It is essential to consider reliable data on terminal operations that form the input and output variables. The output variables are a function of the input variables. The output (production) can be measured in terms of throughput handled and the cost generated (revenues), whereas the input variables can be in terms of land (infrastructure), labor and capital (equipment). (Iyer & Nanyam, 2021)

Løvold et al.,(2015) highlight the most commonly used input and output variables used in the measurement of efficiencies of container terminals based on literature review, as shown in Figure 9.

		Container terminals	Broader set of outputs
Output variables	Physical	Container throughput	Dry bulk cargo (tons), liquid bulk cargo (tons), containers (TEU) and passengers (number)
	Monetary	Annual revenue	
Input variables	Physical	Terminal length (m), Terminal area (ha), Quayside gantry cranes (number), Yard gantry cranes (number) and Straddle carrier (number)	Quay length (m), employees (number), cranes (number)
	Monetary	Salary payments and Net value of fixed capital	Operating Expenditure (OPEX) and Capital Expenditure (CAPEX)

Figure 9: Input and output variables commonly used in the container terminal studies (Source: (Løvold et al., 2015))

Iyer & Nanyam (2021) evaluated the efficiencies of 26 container terminals in India using the DEA method. They indicated through literature review that most of the researchers studying Indian container terminals considered quay length, quay cranes, yard equipment as the main inputs and total throughput as the main output. Many researchers have arrived at different efficiencies and dependent factors for Indian container terminals using DEA method (either one model or in combination with other models). The general consensus is that the effect of privatization has significant impact on the port efficiencies whereas the size of the port had no impact. (Iyer & Nanyam, 2021)

2.6 Conclusions of the section

It can be concluded from the literature review that the port effectiveness, capacity and technologies greatly influence the shipping operations and hence the trade for any nation. In India, especially after the de-regularization in early 1990s drastically improved the port performances and also the national economy (Haralambides & Behrens, 2000). Nevertheless, it is well known that the Indian ports are one of the least competitive in the world. This is particularly attributed to the inadequate infrastructure along with the institutional and procedural delays resulting in inefficient operations. Another factor contributing to the low efficiency is the port charges which are extremely high compared to their counterparts in Asia (De, 2009).

Drewry (2020) highlighted 28 main container terminals (yearly throughput > 10,000 TEU) in India on the east and west coast comprising of both major and minor ports. The ports on the west coast are found to have higher growth (YOY) and throughput for 2019-2020. The pricing mechanism and inability to take proactive actions are regarded as the main contributors for reduced efficiencies in Indian container ports, highlighting the need for improved port governance and reforms. For the purposes of this study, the author will consider 27 main container terminals with yearly throughput > 10,000 TEU. The Mumbai Port Containers (MbPT) is omitted from this study since most of the containers arrive from the nearby container terminals in Nhava Sheva by road and also due to lack of proper yard handling equipment and dedicated yard storage area.

There are four management models based on the port functions and their responsibilities as per The World Bank Port Reform Toolkit (World Bank, 2007): Public service, tool, landlord and private service. The landlord model is found to yield maximum economic surplus on an aggregate level for both port authority and port users (Munim et al., 2019). The Major Port Trusts Act (1963) laid out the strategic and administrative significance for the major and minor ports in India. The limitations of the act outnumbered the advantages, even though it is agreed that there is no 'one size fits all' governance models (de Langen, 2020). The port reforms in India pertaining to different areas of port development essentially include policy, organizational, capacity and regulatory issues (Ray, 2004) although there is a greater need for port reforms to consider improving efficiency and reducing costs, introducing automation in port operations, improving private sector participation and changing role of the government / authority (i-maritime, 2003). In the present study, the author will discuss the port governance and reforms under the SagarMala Programme and their impact on the efficiencies of the selected container terminals.

The economic efficiency of container ports are studied far more than any other type of cargo, often ignoring the social, environmental and political performances. However, the efficiencies reported show discrepancy in terms of contribution from scale of port, type of ownership and impact of port reforms (Bichou, 2013). It is however agreed across the academic spectrum that the empirical estimations of efficiencies depend significantly on the methodology used, type of data and region/country where the ports are located (Odeck & Bråthen, 2012).

The literature review suggests the two most popular methods of efficiency measurement: data envelopment analysis (non-parametric method) and stochastic frontier analysis (parametric method). The DEA method does not impose any functional form a *priori* on the data and it can handle multiple inputs/outputs. DEA measures efficiency of a firm (unit of assessment or decision making unit) by comparing it with other homogenous units that use the same inputs to produce same outputs (Wang et al., 2005). The DEA method comprises of three different models: CCR model (constant returns-to-scale), BCC and Additive Models (variable returns-to-scale). It is vital to select suitable input and output variables to reflect the objectives and process of container terminal production. The output variables are a function of the input variables. The output (production) can be measured in terms of throughput handled and the cost generated (revenues), whereas the input variables can be in terms of land (infrastructure), labor and capital (equipment) (Iyer & Nanyam, 2021). For the purposes of this study, the author will consider the two models in DEA methodology (CCR and BCC) with the quay length (m), terminal area (ha), quayside gantry cranes (numbers) and yard gantry cranes (numbers) as inputs and yearly throughput (TEU) and revenues (INR) as outputs.

3 Methodology

3.1 Introduction

This section will present the methodologies adopted to measure the efficiencies of selected container terminals in India in order to provide solutions for the research question and sub-questions. It is to be noted that some sub-questions are already answered based on academic literature reviewed by the author in Section 2. Whereas other sub-questions will be answered using the methodology described in this section and subsequent research findings and interpretations.

The research methodology adopted in this study to achieve the objectives follow the literature review and the aim of the SagarMala programme. The container terminals, analysis methodology and corresponding input/output parameters are selected based on the literature review and SagarMala programme. The analysis is then performed on the data collected and the results interpreted to obtain most efficient and inefficient terminals. Finally, the issues that affect the efficiencies attributed to SagarMala programme are identified for each terminal and port cluster. The process chart of the research methodology is shown in the figure below.

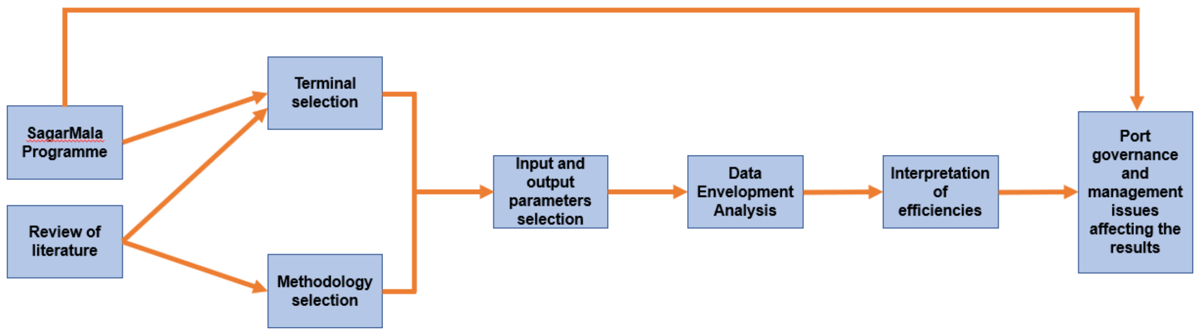


Figure 10: Process chart showing the research methodology
(Source: Own illustration)

The necessity of using DEA method is already described in Section 2.5 along with the recognition among the researchers especially to measure the efficiencies of container terminals. The need for output and input variables to have a direct relationship is also evident from the literature review. Hence, firstly the data collection methodology and corresponding sources are described in this section. Secondly, input and output variables considered for the study are presented in addition to the dataset that forms the input for DEA solver. Then we discuss the application of DEA methodology to the considered dataset, followed by a brief overview and concluding remarks on the section.

3.2 Data description

The salient features of the data required for DEA model are described in this section along with their sources. The timeframe considered for the analysis is from FY2014-15 to FY2020-21. This will enable us to understand the performance of container terminals beyond the timeframe considered by Iyer & Nanyam (2021) and update with latest available information. In addition to this, the timeframe will allow us to study the impact of development programs under the SagarMala programme (initiated in the year 2014-15) on the efficiency of the container terminals.

3.2.1 Container terminals

The container terminals are selected such that most of the major and minor ports as per the administrative classification are covered in the analysis. As described in Section 2.2, there are 28 container terminals in India with an annual throughput of more than 10,000 TEUs. However, it is noted that the container terminal in the Mumbai Port (MbPT) predominantly caters to containers arriving from the nearby terminals at Nhava Sheva by trucks. Also, there are no dedicated yard stacking area and equipment (gantry cranes) for the container movement. Hence MbPT is omitted from the analysis in the present study. The other 27 container terminals are considered and their respective states, location (east/west coast) and administrative classification (major/minor ports) are listed in Table 3. The selected container terminals are called decision making units (DMU) in the DEA method and are considered homogenous since all the terminals only handle container cargo.

Table 3: List of container terminals and their salient features

Sl. No.	Port / Terminal	State	East / West Coast	Major / Minor port
1	APM Terminals Pipavav	Gujarat	West	Minor
2	Mundra International Container Terminal	Gujarat	West	Minor
3	Adani Mundra Container Terminal	Gujarat	West	Minor
4	Adani International Container Terminal	Gujarat	West	Minor
5	Adani CMA Mundra Terminal	Gujarat	West	Minor
6	Adani Hazira Container terminal	Gujarat	West	Minor
7	Kandla International Container Terminal	Gujarat	West	Major
8	Jawaharlal Nehru Port Container Terminal	Maharashtra	West	Major
9	Nhava Sheva International Container Terminal	Maharashtra	West	Major
10	Nhava Sheva India Gateway Terminal	Maharashtra	West	Major
11	APM Terminals Mumbai	Maharashtra	West	Major

Sl. No.	Port / Terminal	State	East / West Coast	Major / Minor port
12	Bharat Mumbai Container Terminals	Maharashtra	West	Major
13	Mormugao Port	Goa	West	Major
14	Vallarpadam International Container Transhipment Terminal	Kerala	West	Major
15	Paradip International Container Terminal	Odisha	East	Major
16	Chennai Container Terminal	Tamil Nadu	East	Major
17	Chennai International Terminal	Tamil Nadu	East	Major
18	Adani Ennore Container Terminal	Tamil Nadu	East	Major
19	Visakha Container Terminal	Andhra Pradesh	East	Major
20	Krishnapatnam Port Container Terminal	Andhra Pradesh	East	Minor
21	Katupalli International Container Terminal	Tamil Nadu	East	Minor
22	Bharat Kolkata Container Terminal	West Bengal	East	Major
23	Haldia International Container Terminal	West Bengal	East	Major
24	PSA SICAL Tuticorin Container Terminal	Tamil Nadu	East	Major
25	Dakshin Bharat Gateway Terminal	Tamil Nadu	East	Major
26	PSA - Kakinada Container Terminal	Andhra Pradesh	East	Minor
27	JSW Mangalore Container Terminal Pvt. Ltd.	Karnataka	West	Major

(Source: (Drewry & Maritime Gateway, 2019))

The western state of Gujarat has the highest number of container terminals (7 numbers) followed by Tamil Nadu in the east coast (6 numbers) and Maharashtra in the west coast (5 numbers). Notably, all the nine coastal states have at least one container terminal. In terms of the location, the number of terminals are slightly skewed towards the west coast (15 numbers), while the east coast has 12 terminals. This is justified by the significant difference in contribution to national GDP by western coast states (34.18%) compared to the eastern coast states (21.46%) (StatisticsTimes, 2021). The administrative classification also shows that there are more container terminals in major ports (18 numbers) than in minor ports (9 numbers). The proximity of high commercial activity near major ports can be one of the reasons for the substantial disparity.

Subsequent to container terminal selection, the terminals are segregated into different port clusters based on their proximity and hinterland catered. The ports in western states of Gujarat and Maharashtra are closely situated. Whereas the ports in south-western states and east coast states are distant. Nevertheless, the terminals are segregated considering the common hinterland catered by the terminals as shown in Figure 11.

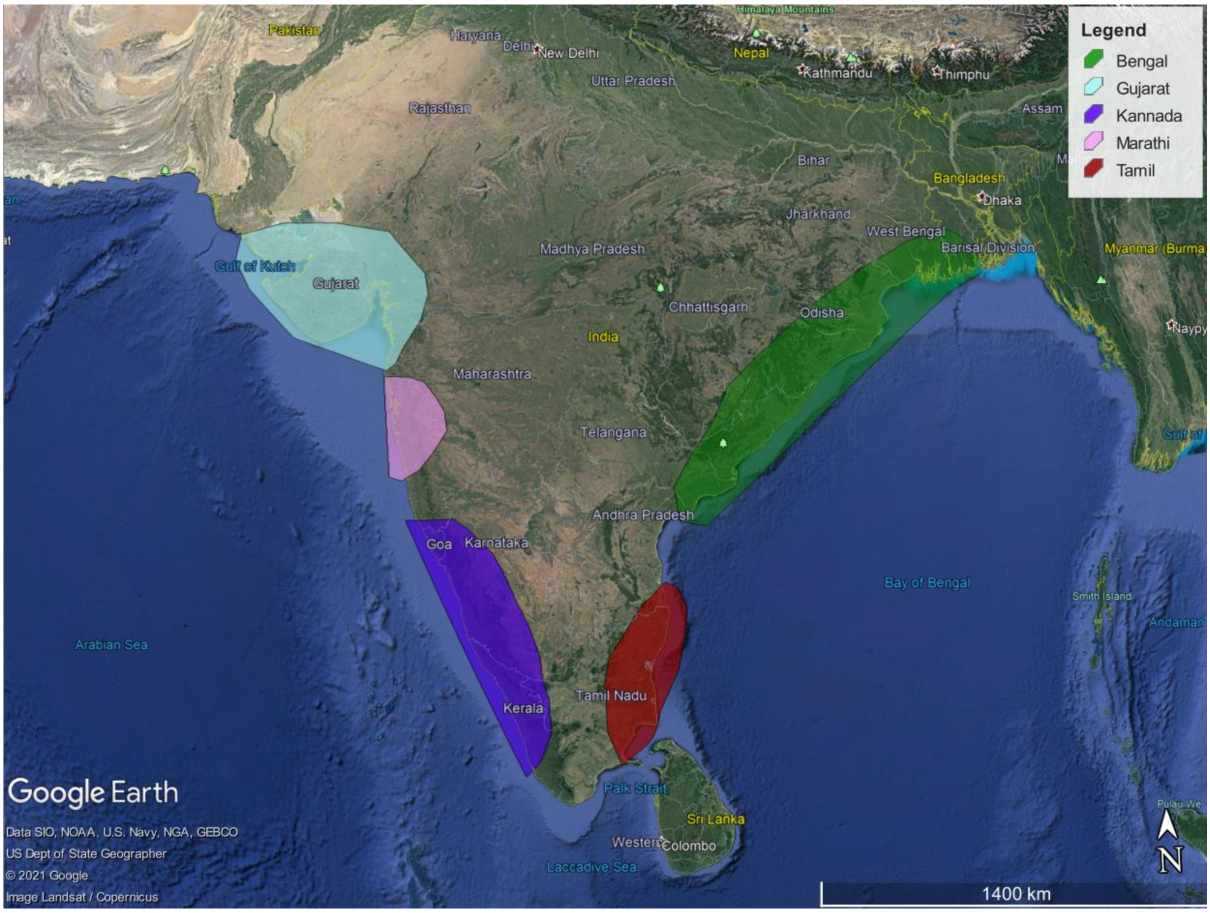


Figure 11: Port cluster segregation

(Source: Own illustration on Google Earth image)

As per the above segregation, the following port clusters and corresponding container terminals are obtained.

<u>Gujarat Cluster</u>

1) APM Terminals Pipavav
2) Mundra International Container Terminal
3) Adani Mundra Container Terminal
4) Adani International Container Terminal
5) Adani CMA Mundra Terminal
6) Adani Hazira Container terminal
7) Kandla International Container Terminal

<u>Marathi Cluster</u>

1) Jawaharlal Nehru Port Container Terminal
2) Nhava Sheva International Container Terminal
3) Nhava Sheva India Gateway Terminal
4) APM Terminals Mumbai
5) Bharat Mumbai Container Terminals

<u>Kannada Cluster</u>

1) Mormugao Port
2) Vallarpadam International Container Transhipment Terminal
3) JSW Mangalore Container Terminal Pvt. Ltd.

<u>Tamil Cluster</u>

1) Chennai International Terminal
2) Chennai Container Terminal
3) Adani Ennore Container Terminal
4) Krishnapatnam Port Container Terminal

5) Katupalli International Container Terminal
6) PSA SICAL Tuticorin Container Terminal
7) Dakshin Bharat Gateway Terminal

Bengal Cluster

1) Paradip International Container Terminal
2) Visakha Container Terminal
3) Bharat Kolkata Container Terminal
4) Haldia International Container Terminal
5) PSA - Kakinada Container Terminal

In addition to evaluating the efficiencies of the container terminals, this study also analyses the efficiencies of port clusters to understand the relative scale inefficiencies. Also, the impact of development initiatives in the SagarMala programme on the port clusters is evaluated with respect to the obtained efficiencies.

3.2.2 Input parameters

The quay length (m), terminal stacking yard area (ha), number of quayside gantry cranes and number of yard gantry cranes are the input parameters considered for the DEA model. The input parameters are obtained for all the terminals from Indian Container Market Report 2019 by Drewry & Maritime Gateway (2019). The inputs for major ports are also validated by email from the Statistics division of Indian Ports Association.

The list of all the selected container terminals with corresponding input parameters are presented in Table 4. The characteristics of the input parameters are described in this section.

Table 4: Input parameters for selected container terminals

Sl. No.	Ports / Terminals	Quay length (m)	Terminal area (ha)	Quayside gantry cranes (nos.)	Yard gantry cranes (nos.)
1	APM Terminals Pipavav	735	36	8	24
2	Mundra International Container Terminal	631	25	6	20
3	Adani Mundra Container Terminal	631	24	6	20
4	Adani International Container Terminal	1460	65	14	48
5	Adani CMA Mundra Terminal	650	28	4	12
6	Adani Hazira Container terminal	637	20	6	12
7	Kandla International Container Terminal	545	14	4	8
8	Jawaharlal Nehru Port Container Terminal	680	62	9	32
9	Nhava Sheva International Container Terminal	600	26	8	32

Sl. No.	Ports / Terminals	Quay length (m)	Terminal area (ha)	Quayside gantry cranes (nos.)	Yard gantry cranes (nos.)
10	Nhava Sheva India Gateway Terminal	330	25	4	19
11	APM Terminals Mumbai	712	30	10	43
12	Bharat Mumbai Container Terminals	1000	45	12	40
13	Mormugao Port	250	2	2	0
14	Vallarpadam International Container Transhipment Terminal	600	61	4	15
15	Paradip International Container Terminal	450	5	3	2
16	Chennai Container Terminal	885	18	8	26
17	Chennai International Terminal	832	28	7	18
18	Adani Ennore Container Terminal	400	20	4	12
19	Visakha Container Terminal	450	8	2	10
20	Krishnapatnam Port Container Terminal	650	36	5	9
21	Katupalli International Container Terminal	710	18	6	15
22	Bharat Kolkata Container Terminal	812	13	2	0
23	Haldia International Container Terminal	432	5	2	4
24	PSA SICAL Tuticorin Container Terminal	370	10	3	8
25	Dakshin Bharat Gateway Terminal	345	10	3	9
26	PSA - Kakinada Container Terminal	300	5	2	0
27	JSW Mangalore Container Terminal Pvt. Ltd.	1267	4	0	0

(Source: Own illustration based on (Drewry & Maritime Gateway, 2019))

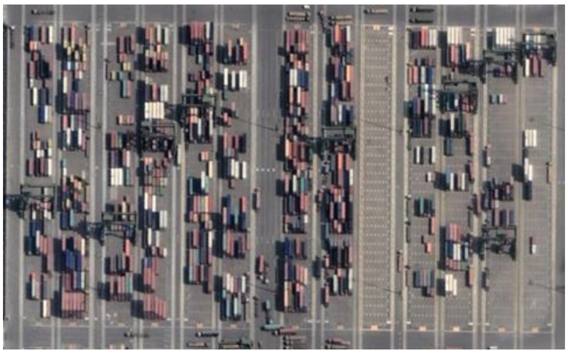
The quay constitutes the main terminal infrastructure that caters to the vessel for loading / unloading of container cargo. The length of the quay dedicated to container cargo is different for each terminal.Figure 12 shows a typical container terminal with the quay length dedicated for container vessels along with the quayside gantry cranes under operation to load/unload containers from the vessel.

Quay length of container terminal
Source: Own illustration based on Google Earth image

Typical quayside gantry crane
Source:(Weihua, 2021)

Figure 12: Illustration of quay length in a container terminal

The terminal yard area is the area dedicated for stacking/storing and movement of containers. Figure 13 shows typical container stacking yard with the yard equipment (yard gantry cranes).



Container terminal stacking yard
Source: Own illustration based on Google Earth image

Typical yard gantry crane
Source: (TransportGeography, 2021)

Figure 13: Illustration of quay length in a container terminal

It is noted that Adani International Container Terminal (Mundra) has the longest quay length (1460m), largest terminal stacking area (65 ha), most number of quayside and yard gantry cranes (14 quay cranes and 48 yard cranes) among all the terminals. Whereas Mormugao Port (Goa) terminal has the shortest quay length (250m) and smallest stacking area (2 ha). There are some terminals that have no quayside gantry terminals (JSW Mangalore Container Terminal) and no yard gantry cranes (Mormugao Port, Bharat Kolkata Container Terminal, PSA - Kakinada Container Terminal, JSW Mangalore Container Terminal).

The impact of the characteristics on the efficiency of container terminals are studied and presented in Section 4.

3.2.3 Output parameters

The annual throughput (TEU) and operating incomes (INR) are considered as the output parameters for the DEA model. The output parameters are considered for each fiscal year from 2014-15 until 2020-21. The data collection methodology of the parameters are described below.

3.2.3.1 Throughput (TEU)

The annual throughput (TEU) for all the terminals are obtained from the Indian Container Market Report (2020) until the year 2020. For the year 2020-21, the throughput for major ports are obtained from Indian Port Association by email (Refer Annexure 7.1). For minor ports in the state of Gujarat, the throughput values are obtained from Gujarat Maritime Board by email (Refer Annexure 7.2). The throughput for the remaining container terminals (Krishnapatnam, Kattupalli and Kakinada) are obtained from news articles for the year 2020-21. The final throughput values considered in the analysis are presented in Table 5.

3.2.3.2 Operating income (INR)

The operating incomes for ports, specifically for container terminals are difficult to obtain due to diverse nature of operations, various commercial activities, and also due to privatization (in Minor ports). Along with the collected information for Major ports reasonable assumptions are made to arrive at the operating incomes of the container terminals. The steps described below are followed to arrive at the required output values.

a) The total container cargo (in tonnes) of Major ports are obtained from the Basic Port Statistics of India report between 2014-15 and 2020-21 (Refer Annexure 7.3).

b) The operating income per tonne of cargo (in INR) of Major ports are also obtained from the Basic Port Statistics of India report between 2014-15 and 2020-21 (Refer Annexure 7.4).

c) The container throughput of Major ports are obtained by email from the Indian Ports Association as described in Section 3.2.3.1.

d) The operating income per TEU is calculated using the formula:

$$Opeating\ income\ per\ TEU = \frac{Total\ container\ cargo\ in\ tonnes\ \times Operating\ income\ per\ tonne}{Container\ throughput\ in\ TEUs}$$

The detailed table showing operating income per TEU is presented in Annexure 7.5. The calculated income per container (INR/TEU) is compared with the total throughput (TEU) as shown in Figure 14 and it is observed that the income per container approximately follows the same trend as the total throughput. This ensures that the assumptions made in calculating the income per container are feasible.

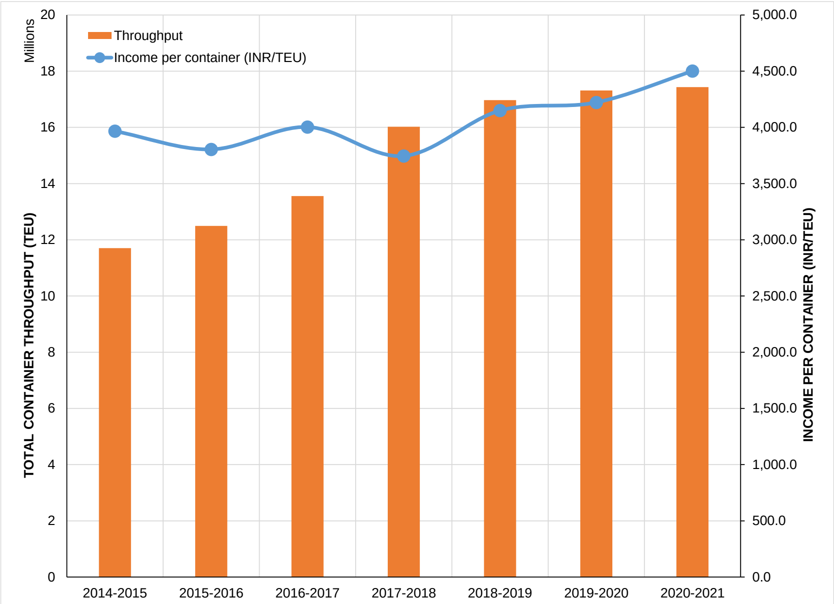


Figure 14: Comparison of total container throughput (TEU) and calculated income per TEU (INR/TEU) (Source: Own illustration)

e) The average operating income per TEU of Major Ports are calculated by taking average for each year separately as shown in Annexure 7.5. The average operating incomes are considered for all the terminals based on their throughputs. It is also observed from the ports' tariff data that the stevedoring charges in minor (private) ports are 1.3 to 1.4 times more than the charges in major ports. Hence an additional factor of 1.5 is considered for minor ports to include the effects of variation in handling charges, privatization, and other services in private ports. Hence the total operating income of minor ports are obtained using the formula.

$$Total\ operating\ income\ in\ Crores = Operating\ income\ per\ TEU\ \times Throughput\ \times 1.5$$

Whereas, the operating income for major ports are obtained using the formula:

$$Total\ operating\ income\ in\ Crores = Operating\ income\ per\ TEU\ \times Throughput$$

f) The total operating incomes of all the container terminals are presented in Table 6.

Table 5: Annual throughputs (TEU) for all container terminals

Sl. No.	Ports / Container terminals	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
1	APM Terminals Pipavav	793.6	694.6	663.4	703.0	903.3	872.6	494.5
2	Mundra International Container Terminal	966.9	985.6	1,163.1	1,089.2	835.8	914.3	1,168.7
3	Adani Mundra Container Terminal	835.5	936.6	860.0	1,286.7	1,051.3	1,089.2	1,410.7
4	Adani International Container Terminal	907.5	1,073.7	1,160.0	1,571.8	1,918.1	1,778.9	2,164.6
5	Adani CMA Mundra Terminal	0.0	0.0	276.6	530.7	740.8	941.6	905.4
6	Adani Hazira Container terminal	150.0	302.8	414.9	800.9	559.3	607.6	653.9
7	Kandla International Container Terminal	0.0	3.0	10.0	117.2	244.0	446.9	515.0
8	Jawaharlal Nehru Port Container Terminal	1,294.0	1,429.3	1,534.0	1,481.8	1,056.4	718.9	544.0
9	Nhava Sheva International Container Terminal	1,160.2	999.7	728.6	641.1	560.7	531.4	751.0
10	Nhava Sheva India Gateway Terminal	0.0	202.3	445.1	659.0	938.5	986.6	780.0
11	APM Terminals Mumbai	2,012.5	1,860.3	1,792.5	2,027.9	2,048.5	1,985.5	1,669.0
12	Bharat Mumbai Container Terminals	0.0	107.3	0.0	23.2	520.1	808.9	933.0
13	Mormugao Port	25.0	26.0	30.0	21.0	37.0	32.0	22.0
14	Vallarpadam International Container Transhipment Terminal	365.0	419.0	491.0	515.0	594.6	620.0	690.0
15	Paradip International Container Terminal	4.0	5.0	2.0	6.3	13.0	12.0	16.0
16	Chennai Container Terminal	825.9	867.5	646.3	646.5	653.7	483.5	485.5
17	Chennai International Terminal	720.0	695.6	844.7	901.6	963.2	881.2	901.6

18	Adani Ennore Container Terminal	0.0	0.0	0.0	2.6	57.0	131.0	201.0
19	Visakha Container Terminal	248.0	293.0	366.7	388.3	450.0	502.8	481.0
20	Krishnapatnam Port Container Terminal	93.0	118.6	255.4	481.7	506.2	543.2	324.8
21	Katupalli International Container Terminal	50.0	115.2	348.0	495.3	592.4	676.9	714.0
22	Bharat Kolkata Container Terminal	528.2	577.0	635.8	640.2	652.0	602.4	538.2
23	Haldia International Container Terminal	101.9	85.0	135.8	156.7	178.3	169.9	151.8
24	PSA SICAL Tuticorin Container Terminal	520.0	510.0	533.0	495.3	352.0	170.5	167.6
25	Dakshin Bharat Gateway Terminal	39.7	110.0	110.1	201.1	386.4	634.1	594.4
26	PSA - Kakinada Container Terminal	0.0	0.0	13.7	21.3	24.3	19.1	6.3
27	JSW Mangalore Container Terminal Pvt. Ltd.	62.8	76.0	94.9	115.5	131.6	153.0	150.0

(Source: Own illustration based on sources described in Section 3.2.3.1)

Table 6: Total operating revenues for all container terminals

Sl. No.	Ports / Container terminals	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
1	APM Terminals Pipavav	472.12	396.33	398.32	394.94	562.20	552.56	333.81
2	Mundra International Container Terminal	575.20	562.38	698.35	611.88	520.18	578.95	788.86
3	Adani Mundra Container Terminal	497.05	534.40	516.38	722.87	654.27	689.68	952.23
4	Adani International Container Terminal	539.88	612.64	696.51	883.03	1,193.71	1,126.40	1,461.08
5	Adani CMA Mundra Terminal	0.00	0.00	166.10	298.17	461.03	596.24	611.13
6	Adani Hazira Container terminal	89.23	172.74	249.15	449.93	348.10	384.77	441.39

Sl. No.	Ports / Container terminals	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
7	Kandla International Container Terminal	0.00	1.71	6.00	65.82	151.85	282.99	347.63
8	Jawaharlal Nehru Port Container Terminal	513.19	543.67	614.04	554.96	438.29	303.46	244.80
9	Nhava Sheva International Container Terminal	460.13	380.26	291.64	240.12	232.62	224.31	337.95
10	Nhava Sheva India Gateway Terminal	0.00	76.96	178.18	246.81	389.39	416.50	351.00
11	APM Terminals Mumbai	798.13	707.62	717.53	759.50	849.90	838.16	751.05
12	Bharat Mumbai Container Terminals	0.00	40.81	0.00	8.69	215.79	341.46	419.85
13	Mormugao Port	9.91	9.89	12.01	7.87	15.35	13.51	9.90
14	Vallarpadam International Container Transhipment Terminal	144.76	159.38	196.54	192.88	246.70	261.73	310.50
15	Paradip International Container Terminal	1.59	1.90	0.80	2.37	5.39	5.07	7.20
16	Chennai Container Terminal	327.55	330.00	258.72	242.13	271.21	204.11	218.45
17	Chennai International Terminal	285.54	264.60	338.13	337.67	399.62	372.00	405.70
18	Adani Ennore Container Terminal	0.00	0.00	0.00	0.99	23.64	55.28	90.45
19	Visakha Container Terminal	98.35	111.45	146.80	145.43	186.70	212.27	216.45
20	Krishnapatnam Port Container Terminal	55.32	67.68	153.37	270.62	315.01	343.99	219.21
21	Katupalli International Container Terminal	29.74	65.75	208.93	278.24	368.68	428.60	481.95
22	Bharat Kolkata Container Terminal	209.47	219.48	254.53	239.77	270.51	254.29	242.19
23	Haldia International Container Terminal	40.42	32.33	54.37	58.68	73.96	71.71	68.31
24	PSA SICAL Tuticorin Container Terminal	206.23	194.00	213.38	185.49	146.05	71.96	75.44

Sl. No.	Ports / Container terminals	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
25	Dakshin Bharat Gateway Terminal	15.76	41.84	44.06	75.32	160.31	267.69	267.46
26	PSA - Kakinada Container Terminal	0.00	0.00	8.21	11.99	15.15	12.10	4.26
27	JSW Mangalore Container Terminal Pvt. Ltd.	24.91	28.91	38.00	43.26	54.61	64.59	67.50

(Source: Own illustration based on sources described in Section 3.2.3.2)

3.3 Input and output dataset

The complete dataset of input and output parameters considered for the analysis is presented in Annexure 7.6. The minimum sample size requirement (N) for data envelopment analysis is given by the equation given below (Lu & Wang, 2016).

N ≥ Maximum {No. of Inputs x No. of Outputs, 3*(No. of Inputs + No. of Outputs)}

In the present study, the number of inputs = 4

the number of outputs = 2

Therefore,

N ≥ Maximum {4 x 2, 3*(4+2)}

N ≥ Maximum {8, 18}

The number of DMUs considered in the present study is 27, hence the requirement is satisfied.

The summary statistics of the collected data (inputs and outputs) is given in the table below.

Table 7: Summary statistics of input and output variables

Variable	Quay length (m)	Yard Area (ha)	Quay cranes (nos.)	Yard cranes (nos.)	Throughput (‘000 TEU)	Operating income (INR Crore)
Total Count	27	27	27	27	189	189
Mean	643.11	23.815	5.3333	16.2222	558.15	275.19
StDev	280.89	17.798	3.3397	13.480	502.69	262.76
Sum	17364	643	144	438	105490	52011
Minimum	250	2	0	0	2	3.75
Maximum	1460	65	14	48	2164.56	1461.08
Skewness	1.20	1.034	0.8631	0.848	1.08	1.32
Kurtosis	1.97	0.522	0.5011	0.066	1.01	2.31

(Source: Own analysis based on input and output parameters)

The histograms of all the variables are also plotted to identify the distribution and correlate with the summary given in the table above.

The extent to which a variable’s distribution is symmetrical is known by its skewness value. If the distribution responses for a variable stretches toward the right or left tail of distribution then the distribution is referred to as skewed. Generally if skewness is greater than +1.0 or less than -1.0, then the variable is substantially skewed (Hair Jr et al., 2016). It can seen from Table 7 that the quay length, throughput and operating incomes are skewed parameters. Also, all the variables are slightly skewed to the right of the distribution.

Figure 15: Histogram of input and output parameters
(Source: Own analysis)

The kurtosis value indicates if the distribution is too peaked or not. If the value of kurtosis is greater than +1.0, then the distribution is too peaked and if it is less than -1.0, then the distribution is too flat (Hair Jr et al., 2016). It can be seen from the data that the quay length, throughput and operating income show peaked distribution. This means most of the data for the variables show narrow distribution and lie in the center of the histogram as shown in Figure 15. The yard area, number of quay cranes and number of yard cranes show fairly flat distribution compared to the other variables.

The individual value plots (Refer Figure 16) and the standard deviation also show that the data are more spread out indicating wide range of container terminals with varying resources (inputs) and productions (outputs).

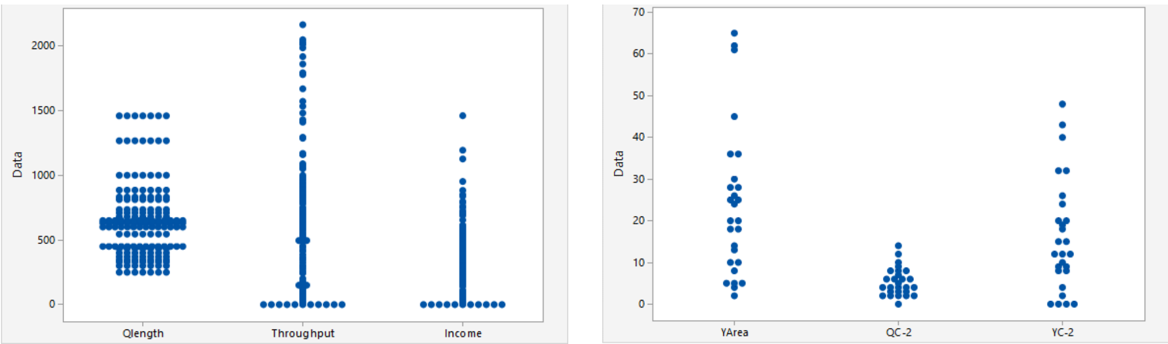


Figure 16: Individual value plots of input and output parameters
(Source: Own analysis)

3.4 Application of DEA

It is noted from literature review described in Section 2.5 that DEA is a linear programming technique to calculate total factor productivity measures. The DEA method evaluates the input-out ratios as efficiency measures considering the given parameters. The main advantage of DEA method is that it allows use of multiple inputs and outputs to measure the efficiencies of decision making units (DMU). The most efficient DMUs form a frontier line which is called the efficiency frontier. The DEA tool also provides the relative efficiencies of other DMUs and suggests the required consumption of inputs (increase or decrease) to project to the efficiency frontier.

The DEA method is characterized by two measures: input-oriented and output-oriented. The input-oriented measures suggest the reduction of input quantities without changing the output quantities produced. Whereas the output-oriented measures suggest the expansion of outputs for the given inputs. The inputs considered in this study (quay length, yard area, number of quay cranes and yard cranes) are all physical assets of a terminal. Increasing and decreasing these assets is not a practically feasible suggestion for any terminal operator. Hence this study attempts to improve the outputs (throughput and revenue) of the terminals without altering the input quantities.

This study considers the relative efficiency measurement using both DEA-CCR and DEA-BCC models. The CCR model assumes that any changes in the input results in a proportional change in at least one of the outputs. Hence the CCR model is considered as a constant returns-to-scale model. The efficiency provided by the CCR model is regarded as overall efficiency of the given DMUs. On the other hand, the BCC model assumes that the changes in inputs has no direct correlation with the outputs. Hence the BCC model is considered as a variable returns-to-scale model. The efficiency provided by the BCC model is regarded as pure technical efficiency of the given DMUs. If both CCR and BCC analyses are conducted on same set of DMUs and a difference in efficiencies is observed, then the DMUs are regarded to possess scale inefficiency. In other words, the overall efficiency can be segregated into pure technical efficiency and scale efficiency. (Coelli, 2007)

This can be mathematically written as follows:

$$Scale\ efficiency = \frac{Overall\ technical\ efficiency}{Pure\ technical\ efficiency}$$

The scale efficiency denotes the appropriate size of the container terminal to produce the required output (Iyer & Nanyam, 2021). A terminal is scale inefficient if its scale efficiency is less than technical efficiency(Lu & Wang, 2017).

This study considers the software package Data Envelopment Analysis (Computer) Program developed by Coelli (2007) for the analysis. The analysis is carried out separately for each year beginning from 2014-15 until 2020-21. In addition to the use of the software package, the analysis is also verified using open-source data analysis software called R-Studio with “deaR” package. A sample code for the R-Studio program is provided in Annexure 7.7. The results obtained from such analysis are collated and the research findings are discussed in the next section.

3.5 Conclusions of the section

In this section, the methodologies chosen through literature review to measure the efficiencies of container terminals are presented. The research methodology essentially includes the terminal and method selection by using the knowledge acquired from the literature review. Then the analysis is performed with the chosen method and the efficiency results are obtained for the given input and output parameters.

The input parameters considered for the analysis are: quay length (m), stack yard area (ha), number of quay cranes (nos.) and number of yard cranes (nos.). Whereas the output parameters considered are: throughput (TEU) and operating income (INR).

The data for input parameters are collected from the Indian Container Market Report for all the 27 container terminals. The throughput values are obtained from Indian Container Market Reports and Gujarat Maritime Board for most of the terminals. The operating incomes of major ports are obtained from Indian Ports Association and the Basic Port Statistics of India. However, the operating incomes are given per tonne of cargo, which are then converted to operating income per TEU using the total cargo in tonnes and total container throughput in TEUs. Using the operating income per TEU and total throughput per year, the total operating income per year is calculated for all the container terminals. This will ensure that all the terminals selected have identical basis for calculation of operating income.

The distribution of input and output parameters indicate a wide range of values, with quay length, throughput and operating incomes slightly skewed towards the higher values and also with peaked distribution (many values lie near the mean). The individual value plots show wider distribution of the input and output parameters indicating that the container terminals selected for the analysis possess varying resources (inputs) and productions (outputs).

This research study considers output-oriented DEA methodology since the physical assets considered as input parameters cannot be easily increased or decrease and hence the objective is to improve the output parameters for the given inputs. The DEA analysis is performed considering CCR and BCC models and the efficiencies are obtained. The ratio of efficiencies obtained in CCR and BCC models gives the scale efficiencies, which reflects the appropriate size of the container terminals to produce the required output.

A software package called DEAP v2.1 developed by Coelli (2007) is used in this research study to perform the data envelopment analysis. The analysis is further verified using “deaR” package in R-Studio, a data analysis tool. The results of the analysis and their interpretation are discussed in the next section.

4 Research findings and interpretations

4.1 Introduction

This section pertains to outcome of the analysis performed as discussed in the previous section along with the interpretation of the results obtained. This section is mainly divided into three segments that essentially answer the following questions;

- ✓ What are the results of DEA?
- ✓ What do the results mean in terms of terminal performance?
- ✓ What is the impact of development initiatives under SagarMala programme (port reforms) on the efficiencies?

Firstly, the results of the data envelopment analysis performed using the DEAP v2.1 and R-Studio software packages are summarized in Section 4.2. The results of the analysis for 27 DMUs from period 2014-15 until 2020-21 are presented in this section. Various results obtained from the analysis are described, including efficiencies, slack/targets, lambda values, and references along with their significance. A combination of major and minor ports that form the port clusters are selected based on their proximity to study the efficiencies. This will provide us with efficient and inefficient port clusters and enable us to study the reasons for inefficiency in port clusters based on the development works.

Secondly, the interpretation of the obtained results are discussed in Section 4.3 with special attention to the efficiencies of the various terminals. The efficiencies are then correlated to the other outputs listed above. This will provide the most efficient and least efficient terminals among the selected DMUs.

Thirdly, the container terminals in major ports are studied with regards to their efficiencies (and other outputs) and development activities carried out as part of the SagarMala programme. The correlation between the development activities and the efficiencies of the terminals are discussed, if any. This will enable us to compare the efficiencies of major and minor ports with respect to the development works under SagarMala programme.

Section 4.5 presents the conclusion of the section and summarizes the observations on results, interpretations and discussions.

4.2 Result summary

This section presents the summary of the results from data envelopment analysis for both CRS and VRS models along with the scale efficiencies of the selected container terminals. The DEA method provides numerous outputs which can be interpreted in different ways. However, for this study only three results are important; efficiencies, slacks and references (peers).

Three kinds of efficiencies are obtained from the results; overall efficiency (CRS), pure technical efficiency (VRS) and scale efficiency (SE). The slacks indicate the utilization of the resources to achieve the required outputs. The references (peers) indicate the benchmarking of each inefficient DMU with a similar efficient DMU to improve its efficiency.

The interpretations of the results discussed in this section are described in Section 4.3.

4.2.1 Efficiencies

The analysis indicates that the mean overall efficiency of all container terminals from 2014-15 to 2020-21 is 0.5844. The pure technical efficiency during the same period is found to be slightly higher at 0.6635. These efficiencies give a scale efficiency of 0.8749. The overall and pure technical efficiencies have maintained similar values from the beginning of the period, apart from a slight increase in the year 2018-19. Subsequently, the efficiencies are again found to be decreasing as shown in Figure 17.

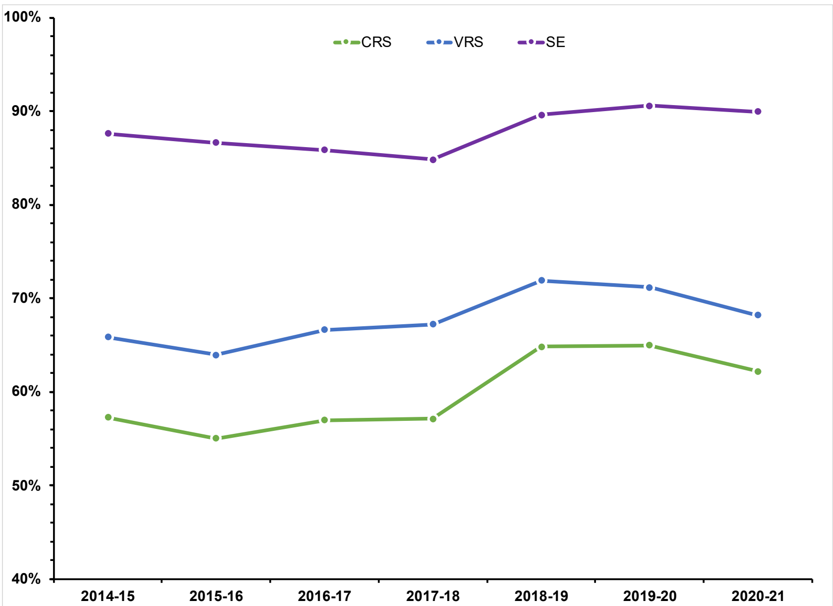


Figure 17: Mean efficiencies of all container terminals for the given period
(Source: Own analysis)

The three different efficiencies (VRS, CRS and scale efficiencies) show significant variation as shown in Figure 18.

As per the VRS model, ten terminals show pure technical efficiency in the range of 80-100%. Meanwhile as per the CRS model, only 6 terminals show overall efficiency in the range of 80-100%. Most terminals (ten numbers) studied under CRS model show an overall efficiency in the range of 40-60%. A very high number of terminals (23 numbers) indicate a scale efficiency between 80-100%, which shows that the overall efficiency and pure technical efficiency of most of the terminals are similar.

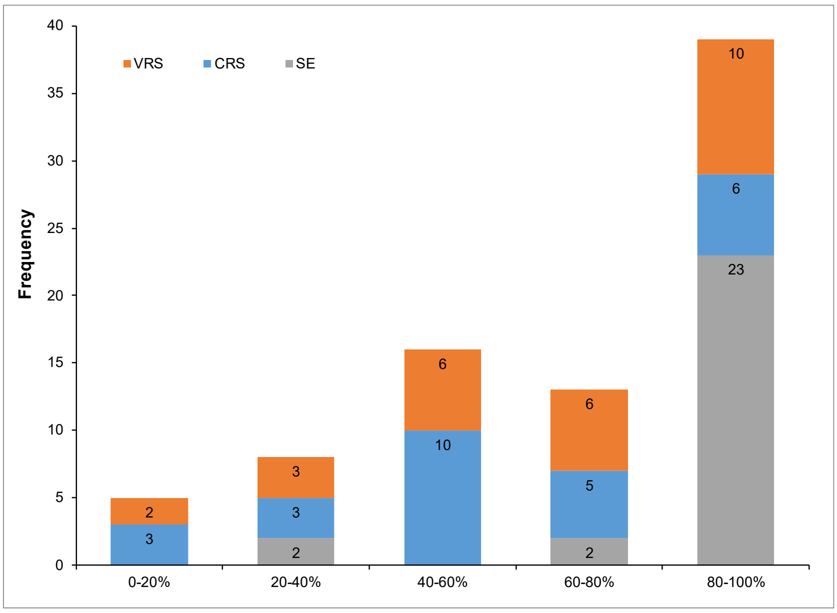


Figure 18: Frequency of three different efficiencies for the selected container terminals
(Source: Own analysis)

A comparison of results of terminals in east and west coast of India is also made along with a comparison of terminals in major ports and minor ports. The study shows that the terminals in the west coast are substantially efficient compared to their counterparts in the east coast as shown in Figure 19.

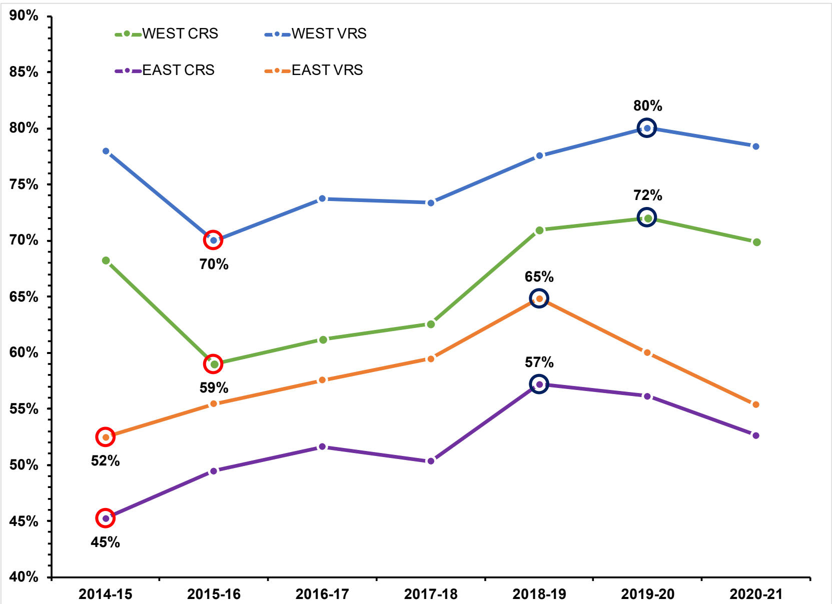


Figure 19: Comparison of terminals in the east and west coast along with maximum and minimum values highlighted
(Source: Own analysis)

The comparison of major and minor ports shows that the efficiencies of major ports were higher in the former half of the period. In the latter half, the minor ports indicate higher efficiencies. Nevertheless, the efficiencies of major and minor ports have converged towards the same direction to almost the same level at the end of the period (2020-21) as shown in Figure 20.

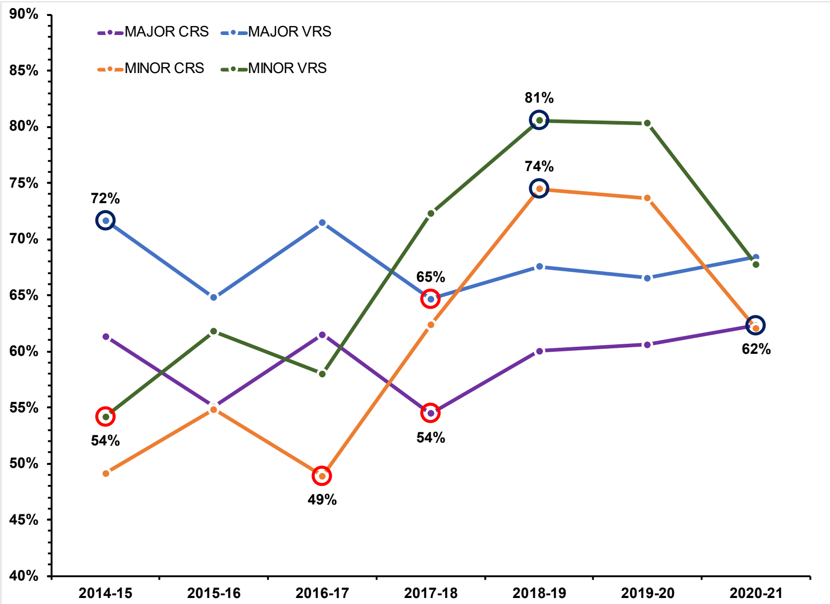
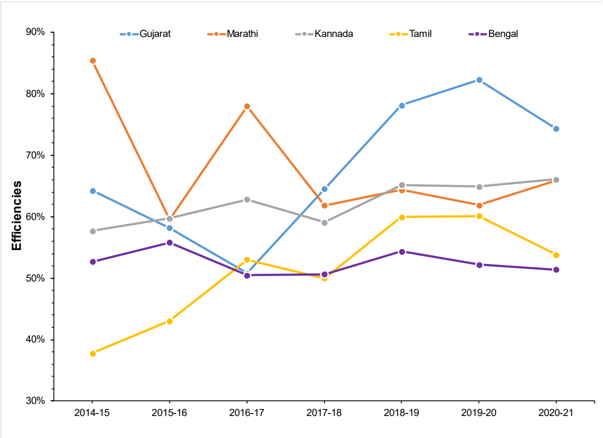


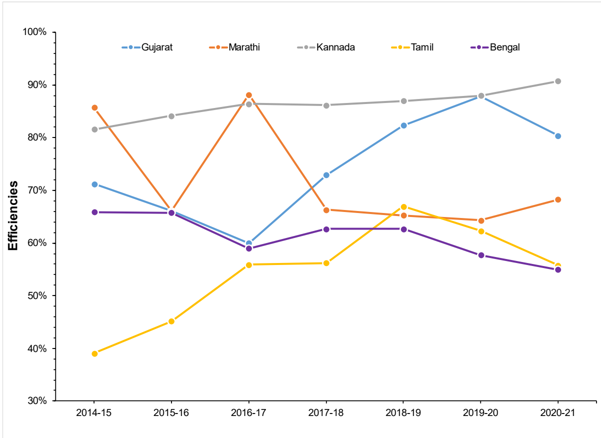
Figure 20: Comparison of efficiencies of terminals in major and minor ports with maximum and minimum values highlighted
(Source: Own analysis)

Figure 21 presents the efficiencies of port clusters selected for this study based on both CRS and VRS models. Most of the port clusters indicate a volatility in efficiencies for different periods. With reference to the CRS model, the port clusters show short periods of growth in efficiencies, but a steady decline in the last two years. The behavior of port clusters with reference to VRS model is also similar to CRS model. However, the Kannada port cluster has indicated a steady growth throughout the period selected, whereas the Bengal port cluster indicated a steady decline. The port clusters Kannada and Bengal also show relatively lower scale efficiencies compared to other port clusters. The scale efficiencies also indicate an initial growth followed by decline after the period 2017-18 or 2018-19 for all the port clusters.

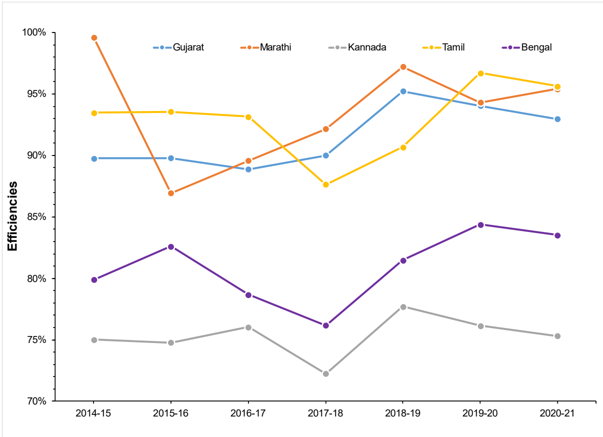
The summary of efficiencies of all the container terminals analyzed in this study is presented in Annexure 7.8 in terms of overall efficiency (CRS), pure technical efficiency (VRS) and scale efficiency (SE).



CRS



VRS



SE

Figure 21: Port cluster efficiencies for the selected period
(Source: Own analysis)

4.2.2 Slacks

In the data envelopment analysis, two types of slacks are obtained; input and output. The input slack indicates that the inputs to the DMUs can be decreased without affecting the outputs. The input parameters with slacks indicates that the resources have not been efficiently utilized and the degree to which these inputs can be utilized. Output slack indicates the degree to which the output can be increased using the given inputs. The efficient DMUs do not possess any input or output slacks.

The number of DMUs that indicate input and output slacks over the selected period are shown in Figure 22 along with the number of efficient DMUs in each year. The figure indicates that many DMUs have input slacks, especially with respect to the number of quay cranes and the yard area. These two inputs are relatively under-utilized compared to other inputs. The number of DMUs with slacks in quay length and yard cranes are relatively fewer, indicating the quay length and number of yard cranes are well utilized.

However, the number of DMUs with output slacks (throughput and income) are relatively constant throughout the selected period. This indicates that these terminals can still improve the outputs without affecting the input parameters.

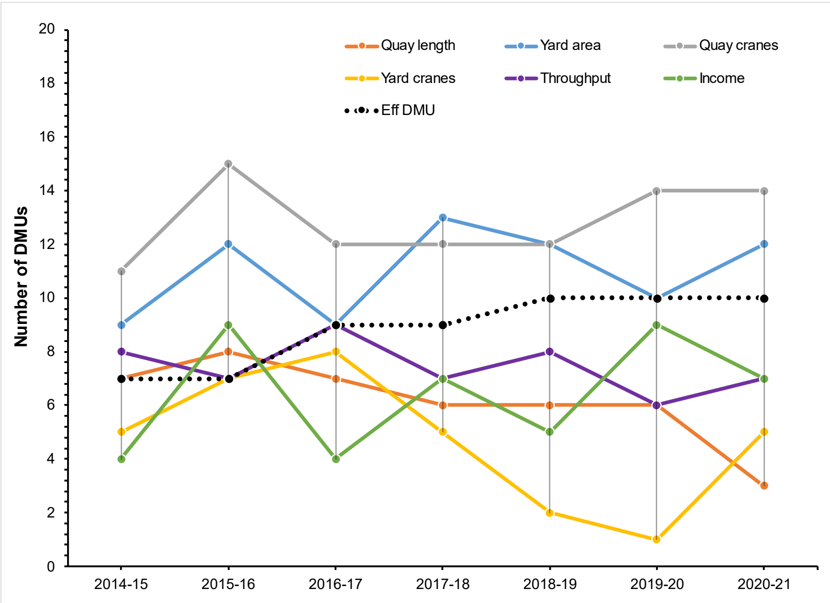
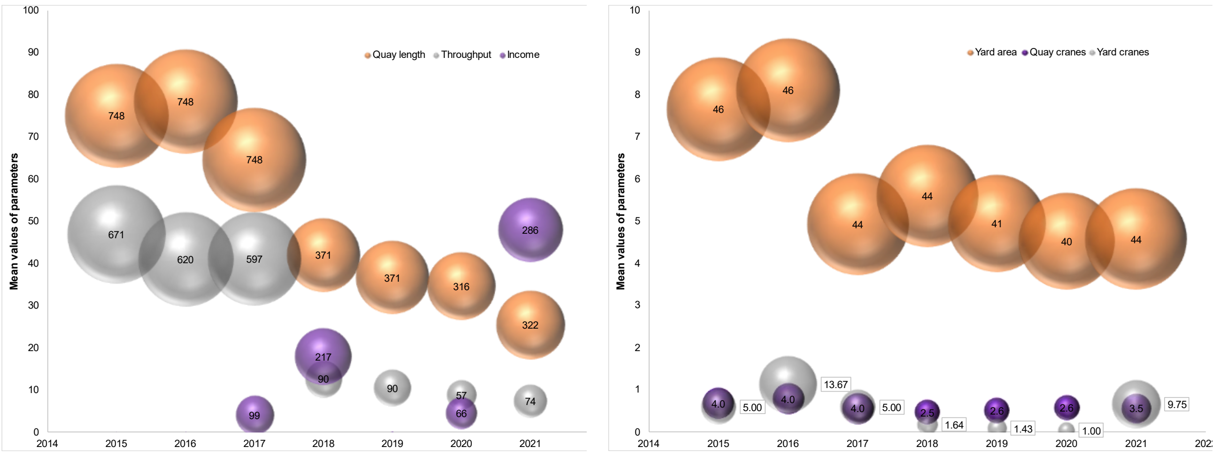


Figure 22: Number of DMUs with input and output slacks for the selected period
(Source: Own analysis)

The minimum, mean and maximum values of input and output slacks are evaluated from the analysis. As mentioned earlier, the efficient DMUs possess zero slack. Hence the minimum value of slack for all inputs and outputs is zero. The mean and maximum values for all the DMUs are plotted for the selected period as shown in Figure 23.



Quay length, Throughput and Income

Yard area, Number of quay cranes and Number of yard cranes

Figure 23: Mean and maximum slacks in inputs and outputs for all the selected DMUs
(NOTE: Bubble size indicates the maximum values)
(Source: Own analysis)

It can be seen from the figure that except throughput and quay length, all the parameters show similar or increased slack. The slack for quay length and throughput have decreased over the years, indicating that the utilization of these parameters is improving. However, the income parameter shows increase in slack, indicating under-utilization of the given inputs to generate income. Other capital assets like yard area, number of yard and quay cranes have also shown similar slack throughout the selected period. This indicates that the utilization of these assets has not improved over the years.

4.2.3 References (peers)

An inefficient terminal should identify the best practices for resources from its peers (references) to improve its efficiency. In the data envelopment analysis, these peers are referred to as "references" and the weights for these references are called as "lambda" values.

The analysis creates a "virtual" terminal comprising of many DMUs including at least one efficient DMU and corresponding peer weights. For instance, refer the table below with the peer weights for DMU "D1".

DMU	D11	D13	D19	D2	D22	D24	D27
D1	17.39%	0	0	82.61%	0	0	0

In order to improve it's efficiency, D1 should look at a "virtual" terminal comprising of D11 and D2 with peer weights of 17.39% and 82.61%. However, since it is not possible to have a virtual terminal with different DMUs, D1 should mainly focus on the peer with highest peer weight, in this case D2 (82.61%).

The results of the DEA indicate that some efficient DMUs can be considered as peers for many inefficient DMUs. In other words, a DMU can be used number of times for the evaluation of other DMUs. This is also known as reference frequency. Figure 24 shows the number of times (between 2014-15 and 2020-21) different DMUs are suggested as peers for inefficient DMUs and their maximum peer weights.

DMUs D11, D13, D19, D22 and D27 appear on all the seven periods (2014-15 to 2020-21) with D11 showing the maximum peer weight of 93.02%. Although D27 appears on all seven periods, the maximum peer weight for this DMU is only 12.73%. This indicates DMU27 is only suggested as a secondary benchmarking DMU.

The summary of minimum and maximum peer weights for all the DMUs for the selected period is presented in Annexure 7.9.

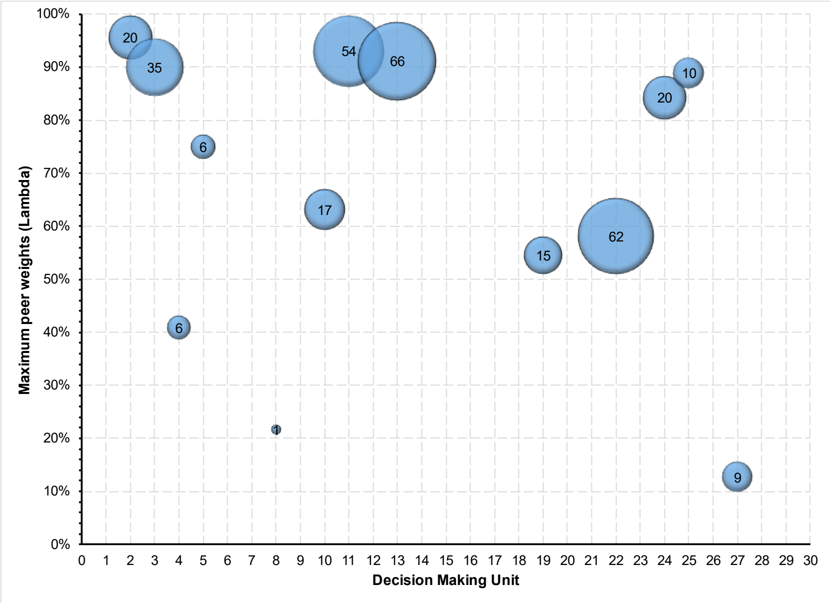


Figure 24: Decision making units and their maximum peer weights
(NOTE: The bubble size indicates the number of times the DMU is suggested as a reference for other DMUs) (Source: Own analysis)

4.3 Interpretation of results

In this section, the author interprets the results obtained from the data envelopment analysis and summarized in Section 4.2. This section follows the similar structure and addresses the rationale for efficiencies, slacks and references.

4.3.1 Efficiencies

The analysis indicates that only three of the selected 27 container terminals are efficient throughout the considered period (2014-15 to 2020-21) for both CRS and VRS models. The three terminals are APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal. Notably all the three container terminals with 100% efficiencies are in major ports. Apart from the three terminals discussed above, most of the terminals do not show consistent performance.

In the study conducted by Iyer & Nanyam (2021) the most efficient terminals were found to be APM Terminals Mumbai, the Bharat Kolkata container terminal and the PSA SICAL Tuticorin Container Terminal. Notably, Iyer & Nanyam (2021) did not consider JSW Mangalore Container Terminal in their study. Hence, the results obtained in this study resemble the results from the literature.

Mundra International Container Terminal showed 100% efficiency in the former half of the study period but the efficiency reduced in the subsequent years. Whereas Adani Mundra Container Terminal showed 100% efficiency in the latter half of the period considered.

Terminals like Mormugao Port, Visakha Container Terminal and PSA SICAL Tuticorin Container Terminal indicated 100% efficiency in the VRS model throughout the period, but lesser overall efficiency (CRS). This resulted in a lower scale efficiency for these terminals.

The average pure technical efficiency of all the container terminals from 2014-15 to 2020-21 is 0.6635. This means that the terminals can improve their outputs (throughput and income) by 33.65% using the given inputs. Based on the assessment of the efficiencies, it can also be evaluated if the terminals have appropriate size to produce the output. This is given by the scale efficiencies of the terminals.

If the efficiencies obtained in CRS and VRS models are greater than the scale efficiencies, then the terminal is called "Scale inefficient". Similarly, if the CRS and VRS efficiencies are less than scale efficiencies, the terminal is called "pure technical inefficient". (Lee et al., 2016)

If the terminal is said to be "scale inefficient", then it should improve its efficiency by adjusting the scale. On the other hand, if the terminal is "pure technical inefficient", then it should improve its performance by adjusting the resources.

The reason for inefficiencies based on average efficiencies of all the container terminals for the selected period from 2014-15 until 2020-21 is provided in the table below.

Table 8: Reason for inefficiency for the selected period from 2014-15 to 2020-21

DMU	Port/Terminal	Reason
D1	APM Terminals Pipavav	PTIE
D2	Mundra International Container Terminal	PTIE
D3	Adani Mundra Container Terminal	PTIE
D4	Adani International Container Terminal	SIE
D5	Adani CMA Mundra Terminal	PTIE
D6	Adani Hazira Container terminal	PTIE
D7	Kandla International Container Terminal	PTIE
D8	Jawaharlal Nehru Port Container Terminal	PTIE
D9	Nhava Sheva International Container Terminal	PTIE
D10	Nhava Sheva India Gateway Terminal	SIE
D11	APM Terminals Mumbai	--
D12	Bharat Mumbai Container Terminals	PTIE
D13	Mormugao Port	SIE
D14	Vallarpadam International Container Transhipment Terminal	PTIE
D15	Paradip International Container Terminal	PTIE
D16	Chennai Container Terminal	PTIE

DMU	Port/Terminal	Reason
D17	Chennai International Terminal	PTIE
D18	Adani Ennore Container Terminal	PTIE
D19	Visakha Container Terminal	SIE
D20	Krishnapatnam Port Container Terminal	PTIE
D21	Katupalli International Container Terminal	PTIE
D22	Bharat Kolkata Container Terminal	--
D23	Haldia International Container Terminal	PTIE
D24	PSA SICAL Tuticorin Container Terminal	PTIE
D25	Dakshin Bharat Gateway Terminal	PTIE
D26	PSA - Kakinada Container Terminal	PTIE
D27	JSW Mangalore Container Terminal Pvt. Ltd.	--

(Source: Own analysis) (SIE=Scale Inefficiency; PTIE: Pure Technical Inefficiency)

It can be seen that nearly 3/4th of the terminals show pure technical inefficiency, which means they have to improve the resource utilization to improve the efficiency. Only three terminals are efficient throughout the selected period. Whereas only four terminals indicate scale inefficiency (on average), which means they have to improve the scale of operations to improve the efficiency.

This is also evident in individual results for each year for all the terminals. It is noted that most of the terminals indicated pure technical inefficiency rather than scale inefficiency, as shown in the table below.

Table 9: Reasons for inefficiency in all terminals for the selected period

DMU	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
D1	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D2	-	-	-	PTIE	PTIE	PTIE	PTIE
D3	PTIE	PTIE	PTIE	-	-	-	-
D4	SIE	SIE	SIE	SIE	SIE	SIE	SIE
D5	PTIE	PTIE	PTIE	PTIE	-	-	SIE
D6	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D7	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D8	PTIE	PTIE	-	PTIE	PTIE	PTIE	PTIE
D9	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D10	PTIE	SIE	SIE	SIE	-	-	-
D11	-	-	-	-	-	-	-
D12	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE

DMU	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
D13	SIE	SIE	SIE	SIE	SIE	SIE	SIE
D14	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D15	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D16	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D17	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D18	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D19	SIE	SIE	SIE	SIE	SIE	-	-
D20	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D21	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE	PTIE
D22	-	-	-	-	-	-	-
D23	PTIE	PTIE	PTIE	SIE	PTIE	PTIE	PTIE
D24	SIE	SIE	-	SIE	PTIE	PTIE	PTIE
D25	PTIE	PTIE	PTIE	PTIE	SIE	-	-
D26	PTIE	PTIE	PTIE	SIE	SIE	PTIE	PTIE
D27	-	-	-	-	-	-	-

(Source: Own analysis)

It can be inferred from the results that the Indian container terminals are struggling to utilize the resources (inputs) effectively and are not able to improve the outputs (throughput and income).

Only three terminals, Adani International Container Terminal (D4), Mormugao Port Container Terminal (D13) and Visakha Container Terminal (D19), indicated scale inefficiency throughout the selected period from 2014-15 to 2020-21.

The terminals in the west coast are significantly more efficient than the terminals in the east coast. The highest efficiency achieved by terminals in the west coast is nearly 80%, whereas the terminals in the east coast could only achieve 65% efficiency during the selected period. However, if we consider the difference in the efficiencies from beginning to end of the period, the efficiency gain of terminals in the east coast (from 52.48% in 2014-15 to 55.37% in 2020-21) is slightly better than the terminals in the west coast (from 78% in 2014-15 to 78.40% in 2020-21. Hence, although the terminals in the east coast are miles behind the terminals in the west coast, they are making slow progress in the overall scenario. The terminals in the east coast should look back at their performance between 2014-15 and 2018-19 and adopt similar strategies. Meanwhile, the terminals in the west coast should also look back at their performance between 2015-16 and 2019-20 and adopt similar strategies.

The major ports have indicated similar efficiencies throughout the study period and in fact have shown a declined efficiency (from 71.68% in 2014-15 to 68.40% in 2020-21). Although, the three terminals to show efficient performance throughout the study period are all in the major ports, the fact that the highest efficiency was achieved in 2014-15 is disconcerting for major ports. On the other hand, the minor ports have shown a strong improvement in efficiency (from 54.19% in 2014-15 to 67.70% in 2020-21). Although the efficiency of minor ports reduced drastically in the last 2 – 3 years, the gains achieved in the study period is significant.

Considering the five port clusters studied in this research, the efficiencies of port clusters Marathi and Bengal have reduced drastically from the beginning to end of the study period (a drop of 17.47% and 10.94% respectively). Table 10 shows the difference in efficiencies of port clusters in the study duration. Ironically, the port clusters Marathi and Tamil have one efficient terminal each. Kannada port cluster in the southwest coast is the only cluster to show steady growth in efficiency throughout the study period.

Table 10: Difference in efficiencies of port clusters between beginning and end of study period

Port cluster	Eff in 2014-15 (%)	Eff in 2020-21 (%)	Difference (%)
Gujarat	71.21	80.37	9.16
Marathi	85.72	68.25	-17.47
Kannada	81.60	90.74	9.14
Tamil	39.07	55.79	16.72
Bengal	65.89	54.95	-10.94

(Source: Own analysis)

The gains in clusters Gujarat and Kannada are similar (9.16% and 9.14% respectively), although efficiency of Gujarat cluster has reduced in the last study year. The southeast coast comprising of Tamil cluster has shown the most impressive growth of 16.72% from 2014-15 to 2020-21 (nearly 43% increase in efficiency).

4.3.2 Slacks

Throughout the study period, it was observed that the quay cranes and yard area have the highest number of slacks. Nearly half of all the number of slacks identified in the inputs and outputs are in the quay cranes and yard area. Table 11 gives a summary of all the DMUs that have the maximum slack in each of the input and output parameters throughout the study period.

It is observed that Adani International Container Terminal (D4), Vallarpadam International Container Transshipment Terminal (D14) and Chennai Container Terminal (D16) possess the most slacks. Especially, in the former half of the study period, the Adani International Container Terminal indicates an under-utilization of almost all its resources (excluding yard area) and reduction in the throughput because of this under-utilization. However, in the latter half of the study period, Adani International Container Terminal did not show maximum slack indicating an improved performance and efficiency.

It is natural that the terminals with highest number of quay cranes (Adani International Container Terminal, Bharat Mumbai Container Terminals and Chennai Container Terminal) are found to have the highest slack in the quay cranes input. Adani International Container Terminal (D4) and Bharat Mumbai Container Terminals (D12) showed nearly 1/4th under-utilization in the number of quay cranes from 2014-15 to 2019-20. Whereas, surprisingly, Chennai Container Terminal showed nearly 44% under-utilization in number of quay cranes in 2020-21 alone. The most concerning result is the slack in yard area, that is observed in only one terminal throughout the study period. Vallarpadam International Container Transhipment Terminal (D14) has showed an average of more than 70% slack in the yard area of the total 61 ha. This means that not more than 20 ha was required for this terminal to produce the same outputs.

Table 11: DMUs with maximum slack in each input and output parameters throughout the study period

Years	Quay length	Yard area	Quay cranes	Yard cranes	Throughput	Income
2014-15	D4	D14	D4	D4	D4	D17
2015-16	D4	D14	D4	D10	D4	D15
2016-17	D4	D14	D4	D4	D4	D14
2017-18	D16	D14	D12	D14	D5	D17
2018-19	D16	D14	D12	D16	D20	D18
2019-20	D16	D14	D12	D16	D21	D8
2020-21	D16	D14	D16	D16	D20	D17

(Source: Own analysis)

In the latter half of the study period, Chennai Container Terminal showed slack in three out of four inputs (excluding yard area). This terminal is observed to under-utilize the quay length, quay cranes and yard cranes.

In terms of the income, Chennai International Terminal (D17) has the most number of maximum slacks (three). In the year 2020-21, it is observed that this terminal could have improved the income by at least INR 285 crores using the same resources.

4.3.3 References

In the case of output oriented DEA method, the inefficient DMUs can refer to outputs of other DMUs (irrespective of efficient or inefficient) to improve their efficiency. A total of seven models were created for each year from 2014-15 to 2020-21. It is found that APM Terminals Mumbai, Mormugao Port Container Terminal, Visakha Container Terminal, JSW Mangalore

Container Terminal Pvt. Ltd., and Bharat Kolkata Container Terminal have been suggested every year. Table 12 shows the reference frequencies of the terminals, peer weights, locations and port types.

Table 12: Terminals and their reference frequencies and weights

DMU	Port/Terminal	Peers	Max Weight	Coast	Port type
D2	Mundra International Container Terminal	20	95.65%	West	Minor
D3	Adani Mundra Container Terminal	35	90.00%	West	Minor
D4	Adani International Container Terminal	6	40.88%	West	Minor
D5	Adani CMA Mundra Terminal	6	75.00%	West	Minor
D8	Jawaharlal Nehru Port Container Terminal	1	21.69%	West	Major
D10	Nhava Sheva India Gateway Terminal	17	63.16%	West	Major
D11	APM Terminals Mumbai	54	93.02%	West	Major
D13	Mormugao Port	66	91.10%	West	Major
D19	Visakha Container Terminal	15	54.55%	East	Major
D22	Bharat Kolkata Container Terminal	62	58.14%	East	Major
D24	PSA SICAL Tuticorin Container Terminal	20	84.18%	East	Major
D25	Dakshin Bharat Gateway Terminal	10	88.89%	East	Major
D27	JSW Mangalore Container Terminal Pvt. Ltd.	9	12.73%	West	Major

(Source: Own analysis)

Most of the terminals suggested as peers are in the west coast and in major ports as indicated in the table above. Three out of thirteen terminals listed above are efficient terminals throughout the study period, hence it is natural that they are suggested as peers. However, the other ten terminals also have substantially high output parameters (throughput and income) that enable them to be suggested as the peers for under-performing terminals.

It is also important to identify the peer weights that is suggested for each DMU. Since the DEA method suggests at least two peers, the peer with maximum weight can be considered as reference DMU. Although JSW Mangalore Container Terminal Pvt. Ltd. (D27) is an efficient terminal, its maximum peer weight is only 12.73%. Hence this terminal cannot be considered as a reference terminal for improvement of output parameters of inefficient terminals. The maximum peer weights for each DMU should be identified and adopted as reference terminal.

A summary of all DMUs with their peers and corresponding peer weights for each assessment year are presented in Annexure 7.10.

4.4 Impact of port reforms on port efficiencies

The results of the analysis indicate that most efficient terminals are: APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal. All the three container terminals are in major ports. One of the contributing factors for the efficiency of major ports is the initiatives under SagarMala programme. The programme identified 104 initiatives to increase capacity of all ports to improve productivity, upgrading berth equipment, and handle bigger vessels (Indian Ports Association, 2016b). With respect to container terminals, the programme aimed to install additional quay cranes and automation of gates to reduce process time. Implementing several initiatives have already showed results in terms of improved turnaround time and number of ports with cape handling capacity (Indian Ports Association, 2016b).

4.4.1 Efficient container terminals

The APM Terminals Mumbai streamlined and simplified the import and export operations to reduce gate waiting time and congestion, and enable faster container movements into and out of the terminal. Before 2015 the tractor trailers had to first offload the export container at Jawaharlal Nehru Port Container Terminal (JNPCT), exit through their gates and then proceed to APM Terminals' Central Gate Complex, a distance of 5.5km. Through SagarMala initiative and investing in automated gates and Radio Frequency Identification (RFID) applications, the tractor trailers are able to offload an export unit at JNPCT and proceed directly to APM Terminals Mumbai for onward pick up of an import container. (APMT, 2020). The Project Unnati under the SagarMala programme adopted global benchmarks to improve the efficiency and productivity of 12 major ports by considering 116 initiatives. In the JNPT alone (which involves APM Terminals Mumbai) 16 initiatives have already been implemented out of a planned 17 until 2019. These initiatives have also helped maintain the efficiency of APM Terminals Mumbai. Also an important Coastal Economic Zone consisting of main districts like Nashik, Thane, Mumbai, Pune, and Raigarh in the state of Maharashtra were linked to the JNPT as part of Port-led Industrialization initiative of the SagarMala programme. JNPT is allocated the highest project cost for initiatives under Project Unnati among all the 12 major ports. (SagarMala, 2020).

JNPT also saw significant improvement in average turnaround times of all vessels by 2.62% (from 29.42 hrs to 28.64 hrs) as well as for container vessels by 2.01% (from 25.82 hrs to 25.30 hrs) from Pilot Boarding to Deboarding in FY 2020-21 in comparison with FY 2019-20. In addition to the turnaround time, the average berth stay of vessels reduced by nearly 4% from 1.11 days to 1.07 days. (JNPT, 2021).

Similar to JNPT, the Kolkata Port Trust (Syama Prasad Mookerjee Port, Kolkata) also increased the berth productivities and reduced the vessel turnaround times significantly through initiatives under SagarMala programme. Significant budget was allocated for yard maintenance and development of area surrounding the yard for easier access and exit to the trucks and trains. The railway yard was upgraded with increased capacity for faster transport to/from the hinterland. Additionally, the port also invested in maintaining the navigation channel leading to the port. Thereby reducing the vessel navigation time. (KoPT, 2020). Out of six initiatives under Project Unnati of SagarMala programme at Kolkata Port, three have already been completed and one is on track to complete on-time for efficiency improvement of the port. (SagarMala, 2020).

The efficient terminal operations in JSW Mangalore Container Terminal is attributed to the increase in container traffic to the port owing to improved hinterland connectivity. The Project Unnati aimed to improve the Coastal Economic Zones comprising of districts Udupi, Dakshin Kannada, Kodagu, Mysore in the state of Karnataka where most of the cash crops of South India originate (SagarMala, 2020). Also, JSW Mangalore Container Terminal is directly connected to the biggest Inland Container Depot (ICD) in South India at Bengaluru (RMG/TCS, 2009). The ICD feeds most of the container terminals in South India since it is a major hub for containers generated in the four states. It is also observed that the terminal has no quay cranes and yard cranes under operation. The loading/unloading operations are carried out using mobile harbor cranes and reach stackers. Hence the peer weight of the terminal is observed to be least among all the terminals. Although the efficiency of this terminal is high, it is not ideally favorable to perform terminal operations without quay and yard cranes as described in Section 4.3.3.

4.4.2 Pure technical inefficiency vs Scale inefficiency

Most of the terminals are identified to be "pure technical inefficient", which means the inefficiency is mainly due to under-utilization of the resources (inputs). The terminals in major ports also indicated additional resources than required for the achieved capacity. One of the reasons is found to be re-rating exercise from the Ministry of Shipping carried out in 2017 of all major ports in order to benchmark the port capacities with global standards. The re-rating exercise identified an additional capacity of 293 MT available with the Major ports (MoPSW, 2017). Under Project Unnati, the global benchmarks were adopted to improve the efficiency and productivity Key Performance Indicators (KPIs) of major ports. Moreover, many initiatives under SagarMala programme like Berthing Policy, 2016, Stevedoring Policy, Project Unnati have led to increased efficiency of the equipment and techniques for quicker turnaround of cargo (MoPSW, 2018). The SagarMala programme emphasizes on having the port infrastructure to cater to traffic until at least 2035. Hence the traffic scenarios considered in most of the development activities have been mapped for a period of next 15-20 years.

This results in under-utilization of the main resources like yard area and number of cranes (Indian Ports Association, 2016a).

4.4.3 West coast vs East coast

The container terminals in the west coast are more efficient than the terminals in the east coast. The SagarMala programme had envisaged that there is a need for increased capacity in the port clusters in the west coast. It was found that the 60% of EXIM container movement in India is west bound and the rest 40% is east bound (Indian Ports Association, 2016a). The terminals in the west coast have to cater to the largest hinterland clusters. The three major hinterlands – the northwest, west and southern clusters – account for nearly 90% of the container volumes. The Gujarat and Maharashtra port clusters handle nearly 70% of India's EXIM container cargo (Indian Ports Association, 2016a). The results of this study also shows that due to increased necessity to cater to high traffic the terminals in the west coast are required to have high efficiency. Since terminals in the west coast have higher efficiency, it can be assumed that the development activities are already in place in these ports. It is also observed that the initiatives under SagarMala programme for east coast are higher in number compared to the west coast. Also, due to increased traffic and necessity for increase in capacity, the west coast ports are allotted more project costs (55% of total cost) instead of the east coast. Drewry (2020) also noted that the two main factors for faster growth on the west coast ports are:

a) More industrial development of the containerized cargo in the west coast.
b) The connectivity between the major industrial cluster in north-western region and the west coast ports are more efficient and nearer compared to the east coast ports.

4.4.4 Major ports vs Minor ports

Minor ports show consistently improved performance compared to the major ports. One of the objectives of the SagarMala programme is to improve the private sector participation in both major and non-major (minor) ports. Although, most of the containerized cargo handled in India are in major ports, the minor ports are also showing increased participation. Drewry (2020) noted that the growth of minor ports in the last 10-15 years has surpassed the major ports. This is particularly attributed to, among development of terminals, the optimization of hinterland connection, especially rail operations. Mundra Port comprising of Mundra International Container Terminal, Adani Mundra Container Terminal, Adani International Container Terminal, and Adani CMA Mundra Terminal is one such example of a privately owned port that offers congestion free and cost-effective port options especially to the containerized cargo from the north-western industrial belt.

Similarly, Krishnapatnam Port Container Terminal and Katupalli International Container Terminal in the south-eastern coast have emerged as the main players in the minor ports in the last 4-5 years along with Mundra and Pipavav.

In addition to the development, the minor ports also offer transparent services and efficient and often automated equipment that attract the cargo owners towards the minor ports and away from the major ports.

4.4.5 Port cluster efficiency

The highest efficiency is observed in Kannada cluster. The Kannada cluster comprises of Mormugao Port Container Terminal, Vallarpadam International Container Transhipment Terminal, and JSW Mangalore Container Terminal Pvt. Ltd. All the three ports in this cluster belong to the Major ports. Although Mormugao Port Container Terminal and JSW Mangalore Container Terminal Pvt. Ltd. indicate lack of sufficient dedicated equipment and storage yard, their capability to generate high throughput and income led to the improved efficiency. Especially the JSW Mangalore Container Terminal Pvt. Ltd. as seen in the peer weights, is not an ideal container terminal in terms of resources utilized. The Tamil cluster (south east coast) shows the highest difference in efficiency between the beginning and end of the study period. Although at the end of the study period, the average efficiency of this cluster is only about 55%.

The initiatives under SagarMala programme for these two clusters are mainly aimed at POL, LNG, and thermal coal cargo imports and exports. These clusters are envisaged to have low potential for container cargo. (Indian Ports Association, 2016a).

The clusters with high potential for container cargo are Gujarat and Marathi clusters. The Gujarat cluster a difference in efficiency of +9.16%, whereas the Marathi cluster showed a difference of -17.47%. This indicates the shift in container cargo from the Marathi cluster to the Gujarat cluster because of improved performance of private ports in the Gujarat cluster, especially Mundra and Pipavav. Due to its proximity to the north-western industrial belt and transparent services provided by the private ports, the Gujarat cluster is attracting more cargo away from the Marathi cluster (especially JNPT).

The Bengal cluster also showed a negative difference in efficiencies (-10.94%) during the study period. The efficiency of this cluster is found to be decreasing every year. All but one terminal in this cluster are in major ports (excluding PSA - Kakinada Container Terminal). Also, this cluster has most of the inefficient terminals (excluding Bharat Kolkata Container Terminal). The low efficiency of this cluster is attributed to less potential for containers and focus on crude oil, iron ore, and fertilizers under SagarMala programme.

4.5 Conclusions of the section

In this section, the results obtained after the analysis using DEA method and their interpretations are discussed. The results indicate that three terminals are efficient throughout the selected study period, whereas ten terminals show 80-100% average efficiency. The three efficient terminals are APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal. The results also indicate that the terminals in the west coast are more efficient than the terminals in the east coast. Unsurprisingly, the minor ports are found to be more efficient than major ports. The port clusters in the south west and south east coasts are found to be the most efficient clusters out of the five selected clusters. However, these clusters are not ideal terminals to follow due to less resources and automation. Most of the terminals show “pure technical inefficiency” indicating these terminals should improve their resource utilization for improvement in the efficiencies.

The slacks are considered as the output of the DEA method to identify the utilization of resources (inputs). It is found that most of the terminals indicate input slacks especially in yard area, number of quay and yard cranes. Vallarpadam International Container Transhipment Terminal (D14) showed slack in the yard area for every year selected for this study. The results showed that only 20 ha was required to produce the same throughput and revenue for the terminal.

The peers and peer weights are extracted from the DEA to identify the reference terminals that can be considered by inefficient terminals. APM Terminals Mumbai and Mormugao Port Container Terminal are suggested the peers for most number of times, although their peer weight varies.

It is noted that the initiatives taken under SagarMala programme to improve the hinterland connectivity, terminal area and surroundings, and terminal equipment have directly influenced the efficiencies of three terminals (APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal). Although, minor ports perform better in the long run, the improvements in the major ports are a positive indication of development. West coast ports perform better than the east coast ports due to more industrial development of containerized cargo and also due to proximity to industrial cluster in the north-west India. The positive and negative differences in Gujarat and Marathi clusters clearly indicate the shift of containerized cargo towards private ports from major ports, indicating requirement of significant improvements in development activities in major ports.

5 Conclusion

The countries with long coast lines have the leverage of ports for industrial growth. India is also endowed with more than 7500 km of coastline and is in a strategic location on key international trade routes. Maritime logistics is an important component of Indian economy contributing to around 90% of EXIM cargo by volume. However, the EXIM containers in India travel a distance of 700 to 1000 km between the production centers and ports, compared to 150 to 300 km in China. This affects the transit time and hence the trade, since the exporters cannot commit to tight delivery schedules. Moreover, the existing policies in India for usage of port land are aimed at maximizing rental yields, rather than maximization of overall economic value-added and job creation. Additionally, the Indian ports are often small compared to similar ports in the region, inefficient and lack the draft to accept larger sized vessels. While some ports are congested others are under-utilized leading to varied efficiencies of ports based on their geographic location, connectivity, modernization, privatization etc. In view of the above, the author has evaluated the efficiencies of container terminals in major and minor ports in India to assess their performance and influence of port reforms and initiatives taken under the SagarMala programme. This study is carried out through scientific literature review, data collection, and execution of data envelopment analysis (DEA) methods.

The main **contribution** of this study was the strategic combination of the non-parametric analysis method to evaluate efficiencies and the influence of the SagarMala programme on container terminals in major and minor ports. Evaluating the efficiencies and impact of SagarMala programme allows us to understand the effectiveness of the programme in the last five to six years. However, it is to be noted that since the SagarMala programme is aimed at overall development of the ports and port clusters including the hinterland, it is difficult to identify a particular initiative that is affecting a container terminal. Hence this study focuses on initiatives focused on terminal development, hinterland connectivity and improvement in operation equipment.

5.1 Answer to research questions

The research question and sub-questions presented in Section 1.4 are answered in this section based on the findings of this study. The literature review, collection of secondary data, and the execution of data envelopment analysis form the basis of answers to the research question and sub-questions.

1. **Research question:** How do the state-owned ports in India perform with respect to efficiency parameters owing to increased competition from private ports?

The efficiency of container terminals are compared with respect to the input parameters like quay length (m), yard area (ha), number of quay cranes (nos.) and number of yard cranes (nos.) to produce the output parameters throughput (TEU) and revenue (INR) by using the data envelopment analysis method.

In this study, during the observation period of seven years between 2014 and 2021, the container terminals in the state-owned (major) ports indicated reduced efficiencies compared to the private (minor) ports. The results of the data envelopment analysis shows that the differences in efficiencies are even more noticeable in the main container port clusters in the states of Gujarat and Maharashtra, which are closer to the industrial clusters.

Considering Iyer & Nanyam (2021), who also carried out similar studies but for a shorter period (2015-2018), the outcome of this study is not surprising. The literature review also indicates that the minor ports show higher overall efficiencies compared to the major ports.

It is to be noted that the three most efficient container terminals obtained in this study are in the major ports. APM Terminals Mumbai, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal are the most efficient terminals as per the DEA method for the selected study period. However, most of the terminals in major ports showed that the resources are not utilized in an effective way to produce the output.

Surprisingly, the port clusters in the state of Maharashtra, that has some of the biggest container terminals in India, indicated a significant reduction in efficiency from the beginning to the end of the study period. The main reason for reduced efficiency is found to be from the stronger competition from private ports in Gujarat. The private ports are found to be more efficient in closer proximity, that increased the competition and hence the shift of efficiencies.

2. **Sub-research question:** What are the port governance issues concerning state-owned ports in India with respect to the performance?

The first sub-question is answered by reviewing the academic literature on port governance issues in India and the official Indian government reports on the SagarMala programme which highlight the challenges and objectives of the initiatives taken under the programme.

The major ports are governed by the strategic and administrative significance laid out in the Major Port Trusts Act (1963). The act provides independence and authority to the board of trustees to take important decisions for the development of the ports. However, there are key limitations in terms of political pressures, rigid hierarchy and excess of personnel in major ports. Also, the board of trustees of the major ports lack executive power and authority, for example budgetary limitations up to INR 100 crores (INR 1.0 Billion). (i-maritime, 2003).

Iyer & Nanyam (2021) highlighted the tariff issues in major ports, which are governed by the Tariff Authority for Major Ports (TAMP) in India, as one of the main reasons for reduced efficiencies in major ports. However, TAMP only has the authority to fix tariffs and no other regulatory function. Due to inadequate definition of its role and functions along with limited professional and industry-specific resources the TAMP is facing challenges in discharging its primary responsibility. (i-maritime, 2003).

The development of minor and intermediate ports and collection of port dues in these ports lie with the respective State governments. However, the state governments only enjoy the developmental and administrative role, since a wide range of regulatory matters (from conservancy of marine waterfront to rail connectivity) are dependent on the Central government agencies. This makes the process of acquiring clearances highly inconvenient and time consuming.

3. **Sub-research question:** Why DEA methodology is more suitable to measure port efficiency? What are the standard inputs and outputs generally considered in DEA?

Through the literature review it was found that among the various methods of measurement of efficiencies, only two methods are used most often: data envelopment analysis (non-parametric method) and stochastic frontier analysis (parametric method). DEA measures efficiency of a firm (unit of assessment or decision making unit) by comparing it with other homogenous units that use the same inputs to produce same outputs.(Wang et al., 2005).

The DEA method has many advantages over the stochastic frontier analysis method, especially with regards to measurement of port efficiencies. The main advantage of DEA method is its ability to process multiple inputs and outputs. Also, the DEA method is less sensitive to errors resulting from bad functional specifications whereas the stochastic frontier analysis method can confuse inefficiency with a bad specification of the model.

The DEA method can be applied for a profit making and a loss making entities to target inefficient entities to make them efficient. This method identifies the slacks in resources (inputs) and production (outputs) and indicates their utilization which can be used for improvement in processes. (Shinto KG & Sushama CM, 2017)

Since economic efficiency is related to the use of limited resources economically to produce outputs, the DEA methodology enables a port to evaluate its performance in addition to benchmarking with its peers. This will highlight the possible utilization of resources and improvements in operational processes by adopting best practices from its peers. This makes the DEA methodology one of the most sought after methods of benchmarking for container ports all over the world. (Kevin Cullinane & Wang, 2006)

The output variables of the DEA methodology indicate the production of the container terminal in terms of physical (throughput) and monetary (revenue) variables. The input variables can be segregated based on physical and monetary variables. The physical input variables can be the quay length, terminal area, number of quay cranes, number of yard cranes, number of straddle carriers (or any other equipment), number of employees (labour). Whereas the monetary input variables can be CAPEX and OPEX. (Løvold et al., 2015).

It is agreed among various researchers that the key criteria for selection of input and output variables is the availability of accurate data. Hence majority of researchers consider the input parameters like quay length, yard area, number of quay cranes and number of yard cranes. Meanwhile, the output parameters that are frequently considered in academic researches are throughput and revenue. However, it is important to consider the variables that cover the two main resource criteria of land and capital. (Iyer & Nanyam, 2021)

4. **Sub-research question:** Which are the ideal container terminals that can be referred by inefficient terminals to improve the efficiencies?

The DEA methodology provides the peers and peer weights for all inefficient terminals, in order to identify the best practices for resources and production. The main criteria for considering a terminal as ideal is indicated by its peer (reference) frequency and maximum peer weight. The peer frequency is the number of times each terminal is considered as an ideal container for other terminals. Whereas the peer weight shows the weightage for each output parameter of the ideal terminal.

The analysis in this study shows that the APM Terminals Mumbai and Mormugao Port Container Terminal are the most ideal terminals in terms of peer frequency and peer weight. Notably, only APM Terminals Mumbai is among the most efficient terminal. The other two efficient terminals, Bharat Kolkata Container Terminal and JSW Mangalore Container Terminal Pvt. Ltd., are not recommended as ideal terminals due to their low peer frequency or peer weight. Other minor ports like Mundra International Container Terminal, Adani Mundra Container Terminal, PSA SICAL Tuticorin Container Terminal, and Dakshin Bharat Gateway Terminal are also recommended as ideal terminals because of their high production with efficient usage of resources.

5. **Sub-research question:** What are the initiatives in the Sagarmala programme that can have positive effects on the efficiencies?

The SagarMala programme identified the challenges faced by the port clusters in India and has set the objectives to improve the efficiencies of ports along with the port modernization and port-led development. In terms of operation of ports, the programme identified 104 initiatives that help to improve the productivity, upgrading of berth equipment, handle bigger vessels, and upgrade cargo handling equipment. Particularly in container terminals the programme aimed to install additional quay and yard cranes, automate gates to reduce process time and bottle-necks. The initiative to invest in automated gates has showed positive results in APM Terminals Mumbai. Additionally, due to improved processing times the terminal saw an improvement in vessel turnaround times.

The SagarMala programme also aimed to develop the area surrounding the yard for easier access and exit to the trucks and trains, including investing in upgrading the railway yard.

This will provide faster access of cargo to the hinterland and improve connectivity between the production hubs and the ports. This is particularly seen in the Kolkata Port, which has shown consistent efficiency throughout the selected study period. The Project Unnati of the SagarMala programme also aims to improve the navigation channels by dredging and maintenance activities. This is also seen in the Kolkata Port and has resulted in reduction in vessel navigation times.

The SagarMala programme also has an objective of improving hinterland connectivity by providing direct unhindered access to the Inland Container Depots (ICD) by rail and trucks. This is particularly effective in the south India with the ICD centrally located in Bengaluru, almost equidistant from the terminals in New Mangalore Port, Cochin Port, Chennai Port and VO Chidambaram Port. Hence improving the rail and road connectivity to the ICDs will improve the throughputs at the terminals due to reduced process times. This will in-turn improve the efficiencies of the container terminals.

The implementation of initiatives under SagarMala programme is observed to have a positive impact on the major ports as described above, hence similar appropriate initiatives can be implemented in other major ports that might result in improved performance.

5.2 Limitations

The author different limitations in the empirical analysis carried out in this research as described below:

a) The secondary data collected for major ports in terms of revenue pertain to the total income of the port for all the cargo and not only related to the containerized cargo. Based on the assumptions presented in this study, the revenue generated for containerized cargo is deduced for each of the major port. Although the assumptions considered to assess the revenue for containers are realistic, the limitation still remains.

b) The details of revenues of minor (private) ports are difficult to obtain, especially if the operator is not a publicly-listed company. Hence a reasonable assumption is made based on the revenue per container of major ports and then an additional factor is added to consider the difference in handling/stevedoring charges per container at minor ports. This will give a scenario that is close to the practical case, however this is also considered as a limitation.

c) The initiatives taken under the SagarMala programme do not necessarily target the container terminals but the overall development of the ports and associated entities. Hence it is difficult to assess the impact of each initiative directly on the throughput or revenue of a container terminal. However, the author has ensured to include the initiatives that particularly target the improvement in efficiency of container terminals.

d) The impact of recent major events like Covid-19 pandemic, Suez Canal blockage, and Yantian port congestion on the performance of container terminals is not highlighted in this study. This is due to lack of relevant information from the port authorities or terminal operators on the impact of these events on the operation. Also, since the study focuses on the SagarMala programme and its impact on the efficiency of the terminals, the results are assumed to be oriented towards the development programs and not on the events.

e) It is observed during the secondary data collection that not all terminals have published their throughput details for the FY 2020-21. Hence the author referred to some of these details (especially for minor ports) from news articles and third-party sources. Since this method of data collection was adopted only for three out of the total twenty-seven container terminals, this can be considered as a minor limitation. However, the author has ensured to cross-verify the details with at least two sources for each values.

5.3 Recommended future research

In spite of the limitations described above, the author has done great effort to produce authentic and consistent results based from the analysis. However, the limitations faced in this study and the results obtained lead to new opportunities for future research. The scope of recommended future research includes the following:

a) The impact of major events like Covid-19 pandemic, Suez Canal blockage, and Yantian port congestion on the Indian container terminals can be studied after collecting relevant information. This can be done by reducing the study period to number of days / weeks that the event occurred and then studying the effects on efficiencies.

b) Similar to the container terminals, the SagarMala programme has deep implications on other types of cargos. Hence other cargos, especially liquid and bulk cargo deserve attention for future research due to the volume and value traded.

c) The author has only considered three main results from the data envelopment analysis in this study: efficiencies, slacks and references (peers). Although this encompasses the main efficiency parameters of container terminals, other results can also be studied to identify their consequences and reasons.

d) The author has only considered the capital and land related input parameters in this study. The parameters related to labor are not considered due to lack of relevant information from port authorities and terminal operators. However, a research can be carried out considering labor as an added input parameter to identify the impact of labor on the performance characteristics of container terminals.

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7 Annexures

7.1 Container traffic at Major Ports during 2014-15 and 2020-21

(Figures in 000's)

PORTS	CONTAINER TRAFFIC (in TEUs)						
	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
KOLKATA	528	578	636	640	652	675	540
HALDIA	102	85	136	156	178	169	150
PARADIP	4	5	2	7	13	12	16
VISAKHAPATNAM	248	293	367	389	450	504	481
KAMARAJAR(ENNORE)	-	-	-	3	57	131	201
CHENNAI	1552	1565	1495	1549	1620	1384	1387
V.O. CHIDAMBARANAR	560	612	642	698	739	804	762
COCHIN	366	419	491	556	595	620	690
NEW MANGALORE	63	76	95	115	132	153	150
MORMUGAO	25	26	30	32	37	32	22
MUMBAI	45	43	42	42	27	27	25
J.N.P.T.*	4467	4492	4500	4833	5133	5031	4677
DEENDAYAL	-	3	10	118	244	447	515
TOTAL(MAJOR PORTS):	7960	8197	8446	9138	9877	9989	9616

Source: Indian Ports Association

7.2 Container traffic at container terminals in Gujarat during 2015-16 and 2020-21

Year	Cont.-20 " Cont.-40 "	Adani Mundra Container		APM Terminal Pipavav		Adani Hazira Container	
		IMPORT	EXPORT	IMPORT	EXPORT	IMPORT	EXPORT
2015-16	Cont.-20 "	784,195	834,399	117,931	107,579	65,798	66,223
	Cont.-40 "	683,152	693,084	127,847	102,309	83,862	70,268
2016-17	Cont.-20 "	795,984	882,558	120,603	94,767	77,782	86,889
	Cont.-40 "	756,518	806,986	126,592	93,262	126,168	124,106
2017-18	Cont.-20 "	954,311	1,037,171	126,260	102,765	91,853	103,724
	Cont.-40 "	1,051,930	1,056,212	126,001	99,418	153,378	147,424
2018-19	Cont.-20 "	1,065,654	1,115,655	140,630	99,983	101,944	113,284
	Cont.-40 "	1,153,752	1,206,530	184,558	143,604	177,766	172,228
2019-20	Cont.-20 "	1,053,848	1,113,613	151,277	100,636	93,030	110,421
	Cont.-40 "	1,283,124	1,316,844	172,792	134,302	209,706	196,104
2020-21	Cont.-20 "	1,248,821	1,278,261	134,912	112,271	97,113	109,541
	Cont.-40 "	1,560,866	1,561,382	147,538	99,806	227,192	220,068

Source: Gujarat Maritime Board

7.3 Total container cargo ('000 tonnes) of Major Ports

Sl. No.	Port	East / West Coast	Major / Minor port	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
1.	Kandla International Container Terminal	West	Major	0.00	56.00	175.00	1,839.00	3,958.00	6,967.00
2.	Jawaharlal Nehru Port Container Terminal	West	Major	56,933.00	56,791.00	54,530.00	57,866.00	62,114.00	60,940.00
3.	Nhava Sheva International Container Terminal	West	Major						
4.	Nhava Sheva India Gateway Terminal	West	Major						

Sl. No.	Port	East / West Coast	Major / Minor port	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
5.	Mormugao Port	West	Major	312.00	345.00	402.00	425.00	467.00	418.00
6.	Vallarpadam International Container Transhipment Terminal	West	Major	5,246.00	5,785.00	6,840.00	7,694.00	8,116.00	8,628.00
7.	Paradip International Container Terminal	East	Major	67.00	132.00	42.00	113.00	221.00	222.00
8.	Chennai Container Terminal	East	Major	29,945.00	30,207.00	28,850.00	29,905.00	31,263.00	26,710.00
9.	Chennai International Terminal	East	Major						
10.	Adani Ennore Container Terminal	East	Major	0.00	1.00	1.00	1.00	1,101.00	2,524.00
11.	Visakha Container Terminal	East	Major	4,372.00	5,145.00	6,428.00	6,835.00	7,959.00	8,649.00
12.	Bharat Kolkata Container Terminal	East	Major	8,110.00	9,263.00	9,887.00	9,760.00	9,934.00	9,767.00
13.	Haldia International Container Terminal	East	Major	1,958.00	1,376.00	2,467.00	2,672.00	3,140.00	3,032.00
14.	PSA SICAL Tuticorin Container Terminal	East	Major	11,034.00	12,388.00	12,991.00	14,191.00	14,955.00	16,436.00
15.	Dakshin Bharat Gateway Terminal	East	Major						
16.	JSW Mangalore Container Terminal Pvt. Ltd.	West	Major	920.00	1,105.00	1,411.00	1,744.00	1,920.00	2,278.00

Source: Basic Port Statistics of India

7.4 Operating income per tonne of cargo (in INR) of Major Ports

Sl. No.	Port	East / West Coast	Major / Minor port	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
1.	Kandla International Container Terminal	West	Major	95.65	98.75	131.18	134.00	143.63	128.07
2.	Jawaharlal Nehru Port Container Terminal	West	Major	227.02	241.85	273.68	286.48	281.30	277.52
3.	Nhava Sheva International Container Terminal	West	Major						
4.	Nhava Sheva India Gateway Terminal	West	Major						
5.	APM Terminals Mumbai	West	Major						
6.	Bharat Mumbai Container Terminals	West	Major						
7.	Mormugao Port	West	Major	194.92	165.02	133.69	135.54	216.41	269.20
8.	Vallarpadam International Container Transhipment Terminal	West	Major	178.66	197.90				
9.	Paradip International Container Terminal	East	Major	129.69	134.02	128.96	130.06	130.85	138.72
10.	Chennai Container Terminal	East	Major	132.99	151.57	154.43	147.33	152.62	168.43
11.	Chennai International Terminal	East	Major						
12.	Adani Ennore Container Terminal	East	Major	187.25	191.68	206.58	207.25	205.22	221.50
13.	Visakha Container Terminal	East	Major	136.65	159.12	150.37	150.87	182.92	193.17

<table>
<tr><th>Sl. No.</th><th>Port</th><th>East / West Coast</th><th>Major / Minor port</th><th>2014-2015</th><th>2015-2016</th><th>2016-2017</th><th>2017-2018</th><th>2018-2019</th><th>2019-2020</th></tr>
<tr><td>14.</td><td>Bharat Kolkata Container Terminal</td><td>East</td><td>Major</td><td>390.61</td><td>460.61</td><td>430.34</td><td>468.54</td><td>502.69</td><td>380.84</td></tr>
<tr><td>15.</td><td>Haldia International Container Terminal</td><td>East</td><td>Major</td><td>379.43</td><td>324.89</td><td>356.57</td><td>370.10</td><td>357.44</td><td>347.62</td></tr>
<tr><td>16.</td><td>PSA SICAL Tuticorin Container Terminal</td><td>East</td><td>Major</td><td rowspan="2">144.02</td><td rowspan="2">149.53</td><td rowspan="2">155.46</td><td rowspan="2">114.75</td><td rowspan="2">151.38</td><td rowspan="2">161.57</td></tr>
<tr><td>17.</td><td>Dakshin Bharat Gateway Terminal</td><td>East</td><td>Major</td></tr>
<tr><td>18.</td><td>JSW Mangalore Container Terminal Pvt. Ltd.</td><td>West</td><td>Major</td><td>103.98</td><td>102.50</td><td>113.81</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

Source: Basic Port Statistics of India

7.5 Operating income per TEU for selected ports (INR / TEU)

<table>
<tr><th>Sl. No.</th><th>Port</th><th>East / West Coast</th><th>Major / Minor port</th><th>2014-2015</th><th>2015-2016</th><th>2016-2017</th><th>2017-2018</th><th>2018-2019</th><th>2019-2020</th></tr>
<tr><td>1.</td><td>APM Terminals Pipavav</td><td>West</td><td>Minor</td><td>10,924.7</td><td>9,501.0</td><td>10,297.3</td><td>9,230.4</td><td>7,770.9</td><td>8,427.1</td></tr>
<tr><td>2.</td><td>Kandla International Container Terminal</td><td>West</td><td>Major</td><td></td><td>1,843.3</td><td>2,295.7</td><td>2,103.3</td><td>2,329.9</td><td>1,996.5</td></tr>
<tr><td>3.</td><td>Jawaharlal Nehru Port Container Terminal</td><td>West</td><td>Major</td><td rowspan="4">2,893.6</td><td rowspan="4">2,986.6</td><td rowspan="4">3,316.3</td><td rowspan="4">3,430.1</td><td rowspan="4">3,409.9</td><td rowspan="4">3,361.4</td></tr>
<tr><td>4.</td><td>Nhava Sheva International Container Terminal</td><td>West</td><td>Major</td></tr>
<tr><td>5.</td><td>Nhava Sheva India Gateway Terminal</td><td>West</td><td>Major</td></tr>
<tr><td>6.</td><td>APM Terminals Mumbai</td><td>West</td><td>Major</td></tr>
</table>

Sl. No.	Port	East / West Coast	Major / Minor port	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
7.	Mormugao Port	West	Major	2,432.6	2,189.7	1,791.4	2,740.7	2,731.4	3,516.4
8.	Paradip International Container Terminal	East	Major	2,172.3	3,538.1	2,708.2	2,320.3	2,224.5	2,566.3
9.	Chennai Container Terminal	East	Major	2,576.1	2,929.0	2,988.1	2,846.1	2,951.0	3,296.5
10.	Chennai International Terminal	East	Major						
11.	Visakha Container Terminal	East	Major	2,409.0	2,794.1	2,635.7	2,655.7	3,235.2	3,322.6
12.	Bharat Kolkata Container Terminal	East	Major	5,997.8	7,394.5	6,691.5	7,143.2	7,659.1	6,175.1
13.	Haldia International Container Terminal	East	Major	7,288.7	5,259.4	6,476.3	6,311.2	6,296.1	6,204.5
14.	PSA SICAL Tuticorin Container Terminal	East	Major	2,839.1	2,987.7	3,140.3	2,338.5	3,066.0	3,300.5
15.	Dakshin Bharat Gateway Terminal	East	Major						
	Average income per container (INR/TEU)			**3,965.9**	**3,803.8**	**4,002.9**	**3,745.3**	**4,149.0**	**4,221.5**

7.6 Dataset of input and output parameters considered for DEA

INPUTS

Sl. No.	Terminal	East / West	Major / Minor	Quay length (m)	Terminal area (ha)	Quayside gantry cranes (nos.)	Yard gantry cranes (nos.)
1	APM Terminals Pipavav	West	Minor	735	36	8	24
2	Mundra International Container Terminal	West	Minor	631	25	6	20
3	Adani Mundra Container Terminal	West	Minor	631	24	6	20
4	Adani International Container Terminal	West	Minor	1460	65	14	48
5	Adani CMA Mundra Terminal	West	Minor	650	28	4	12
6	Adani Hazira Container terminal	West	Minor	637	20	6	12
7	Kandla International Container Terminal	West	Major	545	14	4	8
8	Jawaharlal Nehru Port Container Terminal	West	Major	680	62	9	32
9	Nhava Sheva International Container Terminal	West	Major	600	26	8	32
10	Nhava Sheva India Gateway Terminal	West	Major	330	25	4	19
11	APM Terminals Mumbai	West	Major	712	30	10	43
12	Bharat Mumbai Container Terminals	West	Major	1000	45	12	40
13	Mormugao Port	West	Major	250	2	2	0
14	Vallarpadam International Container Transhipment Terminal	West	Major	600	61	4	15
15	Paradip International Container Terminal	East	Major	450	5	3	2
16	Chennai Container Terminal	East	Major	885	18	8	26
17	Chennai International Terminal	East	Major	832	28	7	18
18	Adani Ennore Container Terminal	East	Major	400	20	4	12
19	Visakha Container Terminal	East	Major	450	8	2	10
20	Krishnapatnam Port Container Terminal	East	Minor	650	36	5	9
21	Katupalli International Container Terminal	East	Minor	710	18	6	15
22	Bharat Kolkata Container Terminal	East	Major	812	13	2	0
23	Haldia International Container Terminal	East	Major	432	5	2	4

Sl. No.	Terminal	East / West	Major / Minor	Quay length (m)	Terminal area (ha)	Quayside gantry cranes (nos.)	Yard gantry cranes (nos.)
24	PSA SICAL Tuticorin Container Terminal	East	Major	370	10	3	8
25	Dakshin Bharat Gateway Terminal	East	Major	345	10	3	9
26	PSA - Kakinada Container Terminal	East	Minor	300	5	2	0
27	JSW Mangalore Container Terminal Pvt. Ltd.	West	Major	1267	4	0	0

OUTPUT – THROUGPUT

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
1	APM Terminals Pipavav	West	Minor	793.6	694.6	663.4	703.0	903.3	872.6	494.5
2	Mundra International Container Terminal	West	Minor	966.9	985.6	1,163.1	1,089.2	835.8	914.3	1,168.7
3	Adani Mundra Container Terminal	West	Minor	835.5	936.6	860.0	1,286.7	1,051.3	1,089.2	1,410.7
4	Adani International Container Terminal	West	Minor	907.5	1,073.7	1,160.0	1,571.8	1,918.1	1,778.9	2,164.6
5	Adani CMA Mundra Terminal	West	Minor	0.0	0.0	276.6	530.7	740.8	941.6	905.4
6	Adani Hazira Container terminal	West	Minor	150.0	302.8	414.9	800.9	559.3	607.6	653.9
7	Kandla International Container Terminal	West	Major	0.0	3.0	10.0	117.2	244.0	446.9	515.0
8	Jawaharlal Nehru Port Container Terminal	West	Major	1,294.0	1,429.3	1,534.0	1,481.8	1,056.4	718.9	544.0
9	Nhava Sheva International Container Terminal	West	Major	1,160.2	999.7	728.6	641.1	560.7	531.4	751.0

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
10	Nhava Sheva India Gateway Terminal	West	Major	0.0	202.3	445.1	659.0	938.5	986.6	780.0
11	APM Terminals Mumbai	West	Major	2,012.5	1,860.3	1,792.5	2,027.9	2,048.5	1,985.5	1,669.0
12	Bharat Mumbai Container Terminals	West	Major	0.0	107.3	0.0	23.2	520.1	808.9	933.0
13	Mormugao Port	West	Major	25.0	26.0	30.0	21.0	37.0	32.0	22.0
14	Vallarpadam International Container Transhipment Terminal	West	Major	365.0	419.0	491.0	515.0	594.6	620.0	690.0
15	Paradip International Container Terminal	East	Major	4.0	5.0	2.0	6.3	13.0	12.0	16.0
16	Chennai Container Terminal	East	Major	825.9	867.5	646.3	646.5	653.7	483.5	485.5
17	Chennai International Terminal	East	Major	720.0	695.6	844.7	901.6	963.2	881.2	901.6
18	Adani Ennore Container Terminal	East	Major	0.0	0.0	0.0	2.6	57.0	131.0	201.0
19	Visakha Container Terminal	East	Major	248.0	293.0	366.7	388.3	450.0	502.8	481.0
20	Krishnapatnam Port Container Terminal	East	Minor	93.0	118.6	255.4	481.7	506.2	543.2	324.8
21	Katupalli International Container Terminal	East	Minor	50.0	115.2	348.0	495.3	592.4	676.9	714.0
22	Bharat Kolkata Container Terminal	East	Major	528.2	577.0	635.8	640.2	652.0	602.4	538.2
23	Haldia International Container Terminal	East	Major	101.9	85.0	135.8	156.7	178.3	169.9	151.8

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
24	PSA SICAL Tuticorin Container Terminal	East	Major	520.0	510.0	533.0	495.3	352.0	170.5	167.6
25	Dakshin Bharat Gateway Terminal	East	Major	39.7	110.0	110.1	201.1	386.4	634.1	594.4
26	PSA - Kakinada Container Terminal	East	Minor	0.0	0.0	13.7	21.3	24.3	19.1	6.3
27	JSW Mangalore Container Terminal Pvt. Ltd.	West	Major	62.8	76.0	94.9	115.5	131.6	153.0	150.0

OUTPUT – INCOME (INR Crores / 10 Million)

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
1	APM Terminals Pipavav	West	Minor	472.12	396.33	398.32	394.94	562.20	552.56	333.81
2	Mundra International Container Terminal	West	Minor	575.20	562.38	698.35	611.88	520.18	578.95	788.86
3	Adani Mundra Container Terminal	West	Minor	497.05	534.40	516.38	722.87	654.27	689.68	952.23
4	Adani International Container Terminal	West	Minor	539.88	612.64	696.51	883.03	1,193.71	1,126.40	1,461.08
5	Adani CMA Mundra Terminal	West	Minor	0.00	0.00	166.10	298.17	461.03	596.24	611.13
6	Adani Hazira Container terminal	West	Minor	89.23	172.74	249.15	449.93	348.10	384.77	441.39
7	Kandla International Container Terminal	West	Major	0.00	1.71	6.00	65.82	151.85	282.99	347.63
8	Jawaharlal Nehru Port Container Terminal	West	Major	513.19	543.67	614.04	554.96	438.29	303.46	244.80

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
9	Nhava Sheva International Container Terminal	West	Major	460.13	380.26	291.64	240.12	232.62	224.31	337.95
10	Nhava Sheva India Gateway Terminal	West	Major	0.00	76.96	178.18	246.81	389.39	416.50	351.00
11	APM Terminals Mumbai	West	Major	798.13	707.62	717.53	759.50	849.90	838.16	751.05
12	Bharat Mumbai Container Terminals	West	Major	0.00	40.81	0.00	8.69	215.79	341.46	419.85
13	Mormugao Port	West	Major	9.91	9.89	12.01	7.87	15.35	13.51	9.90
14	Vallarpadam International Container Transhipment Terminal	West	Major	144.76	159.38	196.54	192.88	246.70	261.73	310.50
15	Paradip International Container Terminal	East	Major	1.59	1.90	0.80	2.37	5.39	5.07	7.20
16	Chennai Container Terminal	East	Major	327.55	330.00	258.72	242.13	271.21	204.11	218.45
17	Chennai International Terminal	East	Major	285.54	264.60	338.13	337.67	399.62	372.00	405.70
18	Adani Ennore Container Terminal	East	Major	0.00	0.00	0.00	0.99	23.64	55.28	90.45
19	Visakha Container Terminal	East	Major	98.35	111.45	146.80	145.43	186.70	212.27	216.45
20	Krishnapatnam Port Container Terminal	East	Minor	55.32	67.68	153.37	270.62	315.01	343.99	219.21
21	Katupalli International Container Terminal	East	Minor	29.74	65.75	208.93	278.24	368.68	428.60	481.95
22	Bharat Kolkata Container Terminal	East	Major	209.47	219.48	254.53	239.77	270.51	254.29	242.19

Sl. No.	Terminal	East / West	Major / Minor	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
23	Haldia International Container Terminal	East	Major	40.42	32.33	54.37	58.68	73.96	71.71	68.31
24	PSA SICAL Tuticorin Container Terminal	East	Major	206.23	194.00	213.38	185.49	146.05	71.96	75.44
25	Dakshin Bharat Gateway Terminal	East	Major	15.76	41.84	44.06	75.32	160.31	267.69	267.46
26	PSA - Kakinada Container Terminal	East	Minor	0.00	0.00	8.21	11.99	15.15	12.10	4.26
27	JSW Mangalore Container Terminal Pvt. Ltd.	West	Major	24.91	28.91	38.00	43.26	54.61	64.59	67.50

7.7 Sample R-Studio program code for DEA application

```
#packages
library(deaR)
library(dplyr)

#data import
data <- read.csv("Data.csv")
fix(data)
summary(data_2)

#Assign DMU, Inputs and Outputs
dat <- data %>% select(DMU, QLen, Yarea, QC, YC, Thruput, Income)
dat <- data.frame(dat)
dat1 <- read_data(dat, dmus = 1, inputs = 2:5, outputs = 6:7)

#DEA application
res <- model_basic(dat1, orientation = "oo", rts = "vrs")
```

```
#results
summary(res)
```

7.8 Summary of results of DEA (CRS, VRS and SE) for all container terminals

Sl. No.	Port/Terminal	MEAN			2014-15			2015-16			2016-17			2017-18			2018-19			2019-20			2020-21		
		CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE	CRS	VRS	SE
1	APM Terminals Pipavav	56.85%	62.65%	90.52%	69.93%	76.90%	90.94%	60.27%	67.44%	89.36%	48.97%	56.77%	86.26%	46.90%	53.12%	88.30%	73.39%	77.50%	94.70%	68.39%	73.97%	92.46%	30.10%	32.85%	91.61%
2	Mundra International Container Terminal	90.13%	90.13%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	84.65%	84.65%	100.00%	79.51%	79.51%	100.00%	83.94%	83.94%	100.00%	82.84%	82.84%	100.00%
3	Adani Mundra Container Terminal	95.01%	95.12%	99.88%	89.28%	89.51%	99.74%	98.73%	99.05%	99.68%	77.02%	77.24%	99.72%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
4	Adani International Container Terminal	56.90%	93.04%	60.89%	40.40%	67.64%	59.73%	46.99%	86.58%	54.27%	43.11%	97.07%	44.41%	52.79%	100.00%	52.79%	78.52%	100.00%	78.52%	70.20%	100.00%	70.20%	66.31%	100.00%	66.31%
5	Adani CMA Mundra Terminal	78.83%	80.19%	97.81%							35.05%	36.49%	96.06%	61.43%	64.44%	95.32%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	97.69%	100.00%	97.69%
6	Adani Hazira Container terminal	59.76%	60.61%	98.56%	21.67%	22.01%	98.43%	42.41%	43.14%	98.33%	49.83%	50.62%	98.43%	88.22%	89.59%	98.47%	72.73%	73.97%	98.32%	75.43%	76.08%	99.13%	68.07%	68.88%	98.82%
7	Kandla International Container Terminal	36.05%	37.53%	96.27%				0.58%	0.60%	97.12%	1.68%	1.72%	97.32%	17.77%	18.66%	95.25%	42.98%	45.24%	95.02%	78.19%	80.96%	96.58%	75.10%	77.98%	96.31%
8	Jawaharlal Nehru Port Container Terminal	71.88%	72.79%	98.13%	81.11%	81.17%	99.92%	95.86%	95.90%	99.95%	100.00%	100.00%	100.00%	88.14%	88.55%	99.54%	62.86%	64.11%	98.06%	40.58%	44.67%	90.85%	34.61%	35.11%	98.58%
9	Nhava Sheva International Container Terminal	51.41%	52.19%	98.47%	75.18%	75.99%	98.93%	69.70%	70.50%	98.87%	51.59%	52.72%	97.86%	40.33%	41.73%	96.67%	35.36%	35.59%	99.36%	33.74%	34.11%	98.94%	53.97%	54.72%	98.63%
10	Nhava Sheva India Gateway Terminal	77.80%	93.00%	81.02%				26.69%	58.03%	46.00%	60.44%	100.00%	60.44%	79.69%	100.00%	79.69%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
11	APM Terminals Mumbai	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
12	Bharat Mumbai Container Terminals	21.24%	25.63%	85.05%				5.44%	6.06%	89.87%				1.02%	1.20%	84.95%	23.66%	26.66%	88.76%	35.02%	42.82%	81.79%	41.06%	51.41%	79.88%
13	Mormugao Port	30.01%	100.00%	30.01%	30.77%	100.00%	30.77%	29.29%	100.00%	29.29%	30.67%	100.00%	30.67%	21.34%	100.00%	21.34%	36.89%	100.00%	36.89%	34.53%	100.00%	34.53%	26.57%	100.00%	26.57%
14	Vallarpadam International Container Transhipm	56.62%	58.91%	95.94%	42.24%	44.79%	94.30%	49.85%	52.45%	95.03%	57.81%	59.33%	97.44%	55.88%	58.60%	95.37%	58.67%	60.95%	96.25%	60.14%	64.05%	93.89%	71.75%	72.23%	99.33%
15	Paradip International Container Terminal	3.20%	3.87%	81.70%	1.67%	2.05%	81.26%	2.03%	2.54%	79.95%	0.77%	0.95%	81.19%	2.33%	3.02%	77.22%	4.71%	5.77%	81.67%	4.45%	5.19%	85.80%	6.43%	7.59%	84.79%
16	Chennai Container Terminal	56.88%	58.78%	96.94%	68.40%	71.16%	96.13%	77.73%	80.77%	96.24%	60.10%	62.32%	96.43%	53.13%	55.36%	95.98%	53.18%	55.10%	96.53%	40.59%	41.09%	98.78%	45.02%	45.71%	98.50%
17	Chennai International Terminal	64.95%	70.62%	92.15%	60.52%	62.64%	96.62%	60.06%	62.43%	96.20%	67.38%	74.87%	89.99%	65.99%	73.78%	89.45%	74.16%	77.89%	95.21%	64.16%	74.59%	86.01%	62.40%	68.12%	91.61%
18	Adani Ennore Container Terminal	11.96%	12.82%	91.52%										0.33%	0.41%	82.49%	7.63%	7.97%	95.80%	16.53%	16.82%	98.26%	23.36%	26.09%	89.52%
19	Visakha Container Terminal	83.50%	100.00%	83.50%	56.57%	100.00%	56.57%	68.04%	100.00%	68.04%	83.78%	100.00%	83.78%	82.16%	100.00%	82.16%	93.96%	100.00%	93.96%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
20	Krishnapatnam Port Container Terminal	45.51%	46.40%	98.01%	15.66%	16.01%	97.79%	19.23%	19.69%	97.65%	35.75%	36.56%	97.78%	62.44%	63.84%	97.82%	75.66%	77.47%	97.66%	69.06%	69.72%	99.06%	40.77%	41.48%	98.28%
21	Katupalli International Container Terminal	48.81%	49.97%	97.65%	7.12%	7.27%	97.95%	16.20%	16.62%	97.47%	41.55%	42.69%	97.35%	51.32%	52.71%	97.37%	75.13%	76.72%	97.94%	82.86%	84.46%	98.10%	67.48%	69.32%	97.35%
22	Bharat Kolkata Container Terminal	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
23	Haldia International Container Terminal	48.13%	63.79%	75.09%	36.80%	56.23%	65.45%	31.35%	45.56%	68.82%	49.43%	65.95%	74.95%	52.68%	75.72%	69.58%	59.15%	75.30%	78.56%	55.23%	65.30%	84.58%	52.27%	62.48%	83.66%
24	PSA SICAL Tuticorin Container Terminal	71.63%	76.41%	94.13%	98.31%	100.00%	98.31%	99.05%	100.00%	99.05%	100.00%	100.00%	100.00%	85.81%	100.00%	85.81%	61.44%	76.83%	79.96%	27.92%	28.26%	98.80%	28.86%	29.75%	97.00%
25	Dakshin Bharat Gateway Terminal	49.75%	56.15%	83.61%	7.24%	9.44%	76.71%	20.81%	26.88%	77.40%	20.36%	25.26%	80.61%	34.03%	46.64%	72.98%	65.80%	84.84%	77.56%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
26	PSA - Kakinada Container Terminal	11.01%	30.98%	35.46%							8.73%	24.44%	35.72%	13.54%	42.07%	32.17%	15.16%	39.81%	38.07%	12.88%	34.64%	37.18%	4.76%	13.94%	34.16%
27	JSW Mangalore Container Terminal Pvt. Ltd.	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

7.9 Number of times each DMU is suggested as peer along with minimum and maximum peer weights for the selected period.

DMU	Nos.	2014-15		2015-16		2016-17		2017-18		2018-19		2019-20		2020-21		Overall	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
D1	0															0.00%	0.00%
D2	20	0.09%	89.98%	40.00%	89.98%	40.00%	95.65%									0.09%	95.65%
D3	35							0.01%	90.00%	40.00%	85.28%	0.03%	85.28%	19.67%	90.00%	0.01%	90.00%
D4	6							12.31%	12.31%	12.31%	12.31%	12.31%	12.31%	0.92%	40.88%	0.92%	40.88%
D5	6											4.33%	75.00%			4.33%	75.00%
D6	0															0.00%	0.00%
D7	0															0.00%	0.00%
D8	1					21.69%	21.69%									21.69%	21.69%
D9	0															0.00%	0.00%
D10	17					3.06%	9.43%	3.06%	9.73%	13.15%	63.16%	2.99%	51.52%	8.36%	18.44%	2.99%	63.16%
D11	54	4.61%	71.89%	4.66%	93.02%	17.39%	67.61%	1.89%	86.96%	2.27%	93.02%	2.40%	93.02%	30.26%	51.05%	1.89%	93.02%
D12	0															0.00%	0.00%
D13	66	5.36%	79.95%	5.36%	65.91%	4.35%	91.10%	11.81%	91.10%	6.33%	91.10%	4.78%	91.10%	4.79%	91.10%	4.35%	91.10%
D14	0															0.00%	0.00%
D15	0															0.00%	0.00%
D16	0															0.00%	0.00%
D17	0															0.00%	0.00%
D18	0															0.00%	0.00%
D19	15	12.56%	12.56%	12.56%	12.56%	12.56%	19.75%	19.75%	33.56%	11.19%	30.26%	25.00%	54.55%	27.01%	37.50%	11.19%	54.55%
D20	0															0.00%	0.00%
D21	0															0.00%	0.00%
D22	62	14.51%	58.14%	6.98%	58.14%	8.90%	52.59%	3.35%	40.67%	0.91%	58.14%	6.33%	58.14%	6.33%	40.67%	0.91%	58.14%
D23	0															0.00%	0.00%
D24	20	13.60%	59.84%	13.60%	79.17%	24.96%	72.88%	29.32%	84.18%							13.60%	84.18%
D25	10											16.04%	88.89%	14.43%	88.88%	14.43%	88.89%
D26	0															0.00%	0.00%
D27	9	12.48%	12.48%	12.48%	12.48%	12.48%	12.48%	9.06%	9.06%	9.06%	9.06%	8.33%	12.73%	11.24%	12.73%	8.33%	12.73%

7.10 Decision making units with their peers and corresponding peer weights

DMU	2014-15		2015-16		2016-17		2017-18		2018-19		2019-20		2020-21	
D1	82.61%	D2	82.61%	D2	82.61%	D2	85.28%	D3	85.28%	D3	85.28%	D3	87.45%	D3
D2														
D3	89.98%	D2	89.98%	D2	95.65%	D2								
D4														
D5					50.00%	D2	50.00%	D3	0.00%	D10			0.00%	D10
D6	60.00%	D2	60.00%	D2	60.00%	D2	60.00%	D3	60.00%	D3	49.20%	D3	60.00%	D3
D7			40.00%	D2	40.00%	D2	40.00%	D3	40.00%	D3	37.40%	D3	40.00%	D3
D8	71.89%	D11	71.89%	D11			52.17%	D11	68.61%	D11	63.84%	D11	51.05%	D11
D9	71.04%	D11	67.25%	D11	67.61%	D11	67.61%	D11	64.12%	D11	63.23%	D11	51.30%	D3
D10			66.67%	D24										
D11														
D12			93.02%	D11			86.96%	D11	93.02%	D11	93.02%	D11	40.88%	D4
D13														
D14	43.54%	D24	43.54%	D24	42.34%	D2	50.00%	D3	44.31%	D22	51.52%	D10	50.00%	D3
D15	79.95%	D13	65.91%	D13	65.91%	D13	79.92%	D13	79.92%	D13	56.31%	D13	56.25%	D13
D16	57.14%	D11	57.14%	D11	57.14%	D11	57.14%	D11	57.14%	D11	54.55%	D19	62.50%	D3
D17	58.14%	D22	58.14%	D22	52.59%	D22	90.00%	D3	58.14%	D22	58.14%	D22	90.00%	D3
D18							84.18%	D24	63.16%	D10	56.54%	D25	71.97%	D25
D19														
D20	45.00%	D2	45.00%	D2	45.00%	D2	45.00%	D3	45.00%	D3	75.00%	D5	45.00%	D3
D21	62.47%	D2	62.47%	D2	69.57%	D2	72.73%	D3	69.43%	D3	63.16%	D3	72.73%	D3
D22														
D23	50.00%	D13	50.00%	D13	50.00%	D13	55.06%	D13	55.06%	D13	50.00%	D13	47.32%	D13
D24									54.37%	D13	88.89%	D25	88.88%	D25
D25	59.84%	D24	79.17%	D24	72.88%	D24	65.38%	D24	51.85%	D13				
D26					91.10%	D13	91.10%	D13	91.10%	D13	91.10%	D13	91.10%	D13
D27														