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## Article

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## Original Article

## Technical efficiency analysis of container terminals in India

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## ABSTRACT

Despite the number of studies on the efficiency of container ports, most studies are of developed nations, and very few are of developing nations, such as India. Indian container ports are very critical due to their location advantage and their ability to handle transshipment traffic. There is a need to understand their performance at the micro-level, specifically the terminal level rather than that of the whole port. This paper focuses on the analysis of the technical efficiency of 26 container terminals in India using a data envelopment analysis approach for the years 2015–2018 and interprets it with respect to location advantage, administrative control and private control of terminal operations. The research explores the Malmquist index which measures productivity changes over a period of time and deconstructs them into two components, namely efficiency change, referred to as catch-up, and frontier shift. This study enabled the ranking of these terminals in terms of their performances. The relative efficiency of container terminals on the west coast of India is found to be better than that of the east coast of India, and the efficiency of container terminals operating under major ports is on a declining path when compared with that of minor ports. The private participation has also not seen similar productivity changes across all container terminals. Among the seven high performing container terminals identified through the analysis provided, the terminal at Tuticorin emerged as the most consistent one in terms of relative efficiency and growth in total factor productivity. The dominant factor influencing the efficiency of a terminal is found to be the size of the terminal, offering the advantages of economies of scale.

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## Introduction

## Background

Ports are the gateway to external and international trade and act as a logistical platform for the receiving and transferring of cargo from one place to another. Due to the country's cheap economics, Indian ports handle approximately 95% of India's external trade, which accounts for 70% in terms of volume (Dasgupta, 2018). From 2017 to 2018, they handled a throughput of 1208 million metric tonnes of cargo, including a 20% share of containerised cargo (Ministry of Shipping (MoS), 2018), and in 2018, Indian container ports alone handled 2% of the global container ports throughput, (Nightingale, 2018). The handling of containers by Indian ports began in 1973 at the Mumbai and Cochin ports on the west coast of India, and owing to the demand, container traffic increased eight-fold over 45 years when compared to non-containerised cargo,

which has increased by a factor of only three (Ministry of Shipping (MoS), 2018). Out of all of the Indian container ports, the Jawaharlal Nehru Port Trust (JNPT) is the most consistent port in terms of throughput and is listed among the top 30 container ports in the world since 2003 (Nightingale, 2018; Paul, 2005).

Drastic changes are happening in the global container market. Vessel upscaling to exploit the economies of scale (Paul, 2005), optimum utilisation of capacity reinforcing the role of alliances and industry consolidation and demand and supply mismatch leading to a reduction in freight rates (Kourounioti, Polydoropoulou, & Tsiklidis, 2016) are changing the dynamics of global container shipping. Therefore, Indian container ports are bound to accommodate increasing vessel sizes, overcome the constraints pertaining to hinterland connectivity and upgrade the infrastructure, thereby increasing the efficiency of operations.

In this regard, the government of India has initiated a programme titled "Sagarmala" in 2015 for the integrated development of the coastline, which is expected to enable container traffic to reach 25 million TEUs by 2025 (Ministry of Shipping (MoS) (2016)). In order to meet the augmented traffic, capacity and efficiency enhancements for existing ports, new feeder ports in Andhra

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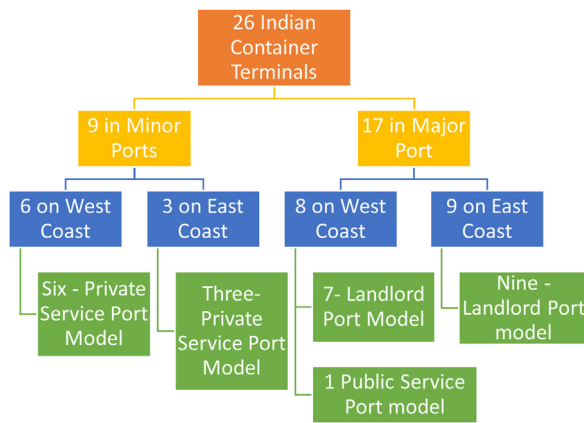


Fig. 1. Classification of container terminals.

Source: Authors.

Pradesh and West Bengal in the east coast and new transshipment ports (Colachel, Vizhinjam and Enayam) in the west coast are considered necessities (ASSOCHAM, 2017). Increasing the number of container ports is not the solution for meeting the demand without utilising the existing ones. The cost effective way of meeting the increased demand is to improve the efficiency of the existing container terminals and upgrade the capacity of existing ones (ASSOCHAM, 2017), which is frequently determined by several attributes such as time spent by the ship in the port, handling of cargo, hinterland connectivity, and port superstructure and infrastructure among other issues.

#### Indian container terminals

Along the 7517 km of Indian coastline, there are 26 Indian container terminals in operation, with 14 terminals located on the west coast and 12 terminals located on the east coast of the country. In terms of administrative control, out of the 26 container terminals, 17 terminals are designated major ports, and 9 terminals are designated minor ports (Fig. 1). The classification of Major ports and Minor ports is based on the strategic significance and administrative control. Major ports are those which are controlled by the Ministry of Shipping and are governed by the Indian Ports Act 1908 and the Major Port Trusts Act 1963; whereas Minor ports are controlled by state government maritime boards (i-maritime, 2003). Port governance in India is moving from a service port model to the landlord port model, and complete privatisation has not been proposed due to a perception of a monopoly in trade and logistics (Brooks, 2004). Classification of the Indian container terminals based on their location, administration and governance is shown in Fig. 1, and the details of each container terminal is listed in Appendix A. The port model is classified as a public service port if the infrastructure, superstructure, labour and other functions are owned and managed by a port authority. These models focus on the interests of the public. The port model is classified as a landlord port when the operations are managed by a private organisation with the port authority acting as a regulator. Landlord port model focusses on the mixed interests by public and private. If the port is regulated, operated by a private party and focusses on the private interests, then it is classified as a private service port (The World Bank, 2016).

Looking at the market segmentation for container throughput, the share of major ports is declining when compared to the share of minor ports, owing to the expansions made by private terminal operators. From 2007 to 2017, the major ports lost a 41% share of the throughput to minor ports (Behera, 2018). Container ports such as Katupalli and Krishnapatnam have rapidly increased their output

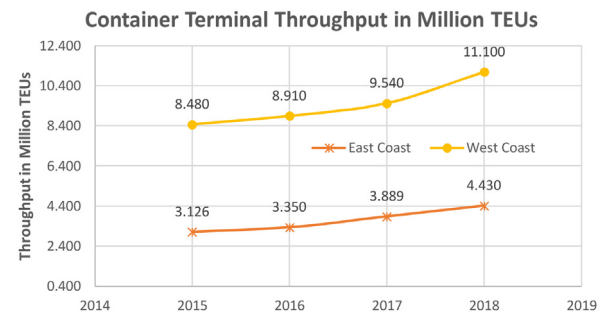


Fig. 2. Container terminals throughput (East vs West Coast).

Source: Compiled from Indian container market reports.

in 2018 compared to 2015, in similar lines to the performance of the Mundra and Pipavav ports (Behera, 2015; 2018). Container terminals operating in minor ports have seen the drastic improvement of a 74% increase in throughput from 2015 to 2018 when compared to the container terminals operating in major ports, which had only a 14% improvement. This is attributed to the intervention of private players into the market, upgrades to the infrastructure and the handling of larger vessels (Behera, 2015; 2018).

Container terminals on the west coast have a higher share of the throughput when compared to the terminals on the east coast, as per the comparative study shown in Fig. 2. However, the overall increase in throughput is slightly higher in terminals on the east coast (42%) than in the terminals on the west coast (41%) despite the advanced infrastructure on west coast terminals which could be attributed to efficient resource utilisation (Behera, 2018). In terms of transshipment volume, container terminals on the east and west coasts handled, on average, 23% and 8%, respectively.

In 2018, there was a steep increase in the throughput of container terminals operated by the Adani Group (126%), the JM Baxi Group (175%), the Krishnapatnam Port (418%) and the Dakshin Bharat Gateway (406%) compared to their throughput in 2015 (Behera, 2015, 2018). APM Terminals registered a negative growth of 3% in the year 2018 when compared to their throughput in 2015 (Behera, 2015, 2018). Terminals operated by DP World, JNPT and PSA have registered an improvement to the tune of 10%, 15% and 18%, respectively (Behera, 2018). Inefficiencies also increase transaction costs in terminals. Private players have entered the container port market, and there is a need to understand their efficiency in their respective terminals to understand the increase in their throughput and improve logistics and transaction costs (Singh, 2017).

Handling transshipment volume is one of the market segments that Indian container ports must capture; private players have handled transshipment cargo as a result of the recent Indian reforms over cabotage relaxation, competitive rates, infrastructure upscaling and so on. Container terminals under major ports must take the initiative to capture the market from the other ports, and they need to overcome the obstructions related to congestion, infrastructure, vessel draft and pricing. Reasons corresponding to the differences in the growth could be attributed to their location, governance and administrative control. Hence, there is a need to understand the efficiency of container terminals operating in major ports vs minor ports, east coast vs. west coast in order to identify the best performing terminals.

#### Motivation and contribution from the study

Extensive research is carried out on understanding the performance, productivity and efficiency of major ports in India (Mandal, Roychowdhury, & Biswas, 2016). However, due to the unavailability of information, less focus is given to minor ports, which

share an equal contribution to throughput (Sekar & Deo, 2016). The shortcoming of the research conducted so far is the consideration of a combined throughput for efficiency analysis, as major or minor ports handle bulk, liquid, roll-on/roll-off (ro-ro) and container cargo. It is challenging to interpret the results and utilise them for constructive purposes as each terminal has different requirements, and the concept of homogeneity is not applicable in the above considerations. Besides, there is no study focused on an analysis of the efficiency of the container terminals operating under different administrative control, such as major and minor ports. Hence, this paper considers this reasoning as the motivation for this study.

This study considers the complete list of Indian operational container terminals, which includes terminals in both major and minor ports. This paper aims to calculate the relative efficiency of 26 container terminals over the period 2015–2018 using cross-sectional data (where the data is available) and compute the total factor productivity using panel data to classify them into low- and high-performing terminals. The analysis is extended further to understand the efficiency of container terminals in major and minor ports, as the administrative control is different for both. Moreover, the paper tries to understand the efficiency of container terminals under private terminal operators. Data envelopment analysis (DEA) and the Malmquist index are used to calculate the efficiency and total factor productivity of the container terminals.

The focus on the efficiency and productivity of the 26 container terminals shall contribute to container port economics in the areas of efficiency improvement and the benchmarking of container terminals. This study intends to help decision-makers to (1) identify high-performing terminals so that the best practices followed may be implemented in low-performing ones and (2) identify consistently performing terminals over the span of a study period, e.g. four years. Reasons for inefficiency are also brought up for each terminal, to help the terminal operators implement improvement measures in terms of technology and scale.

The structure of the paper is as follows: Section 1 focuses on the background, a discussion of the container terminals of India and the motivation, objectives and structure of the paper. Section 2 discusses the review of the existing literature on container terminals. Section 3 describes the research design. Section 4 compiles the results and discussion, and Section 5 concludes the study.

## Literature review

Technical efficiency deals with the production of maximum output with the given level of resources, and it can be output oriented or input oriented. Data envelopment analysis (DEA), a non-parametric method, is used to estimate the technical efficiency of the Decision-Making Units (DMUs) considered for analysis. It encompasses one or many input and output variables to derive the efficiency of the DMUs under consideration, relative to the best DMU.

It started with the basic model proposed by Charnes, Cooper and Rhodes (the CCR model) in 1978. There are several DEA models such as the BCC (Banker, Charnes, Cooper) model, the free disposal hull (FDH), and the additive model (Cooper, Seiford, & Tone, 2007) utilised by researchers. Efficiency analysis has been attempted by many researchers and can be conducted with the help of non parametric methods such as DEA CCR (Charnes, Cooper and Rhodes) (the CCR model), DEA BCC and DEA super-efficiency models to identify the causes of inefficiency and determine efficiency rankings. It is very important to understand the extent of studies conducted in this area which is discussed further.

Munisamy and Singh (2011) discussed the efficiency analysis of 69 major Asian container ports based on DEA CRS, VRS and super-

efficiency models. They tried to rank the efficient ports using a super-efficiency model. They found that there is no evidence to conclude that the size of a port and its efficiency are related. They also concluded that the ownership type would not influence efficiency. Choi (2011) attempted to study the efficiency of 13 northeastern Asian container ports using DEA and tobit regression. The author found that the largest seaport could not display pure technical efficiency despite using technology in operations owing to the lack of strategic alliances and demand.

Niavis and Tsekeris (2012) performed an efficiency analysis on 30 container ports in the region of southeastern Europe. They performed a two-stage analysis, wherein the first stage derives the efficiency scores and the second stage derives the impact of explanatory variables such as size and GDP on the efficiency score. The authors used DEA CCR, BCC and super-efficiency models and concluded that there is low efficiency in the region and determined the causes of inefficiency as scale effects and lack of managerial skills. Demirel, Cullinane, & Haralambides (2012) tried to examine the involvement of private players on the efficiency of container terminals in Turkey and the eastern Mediterranean region. The authors utilised DEA to compute the efficiencies and tobit regression to determine the impact of the explanatory variables.

Schøyen and Odeck (2013) attempted to analyse the efficiency of 24 Norwegian container ports using the DEA technique and tried to compare them with UK container ports; the authors concluded that the ports are too small in size to perform better. Almawshaki and Shah (2015) attempted to understand the operational efficiency of 19 container terminals in the Middle East region. They used a DEA CCR, input-oriented model to estimate the efficiencies. They tried to correlate the efficiency with the size of the port and terminal area to understand their impact. The authors discussed the slack variable analysis for the inefficient container terminals. Zheng and Park (2016) analysed the efficiency of 30 container terminals in Korea and China using DEA to understand the necessary improvement measures to be implemented. Suárez-Alemán, Sarriera, Serebrisky, and Trujillo (2016) analysed the efficiency of global container ports using DEA & Malmquist Index and found that the drivers of efficiency are private sector operations, reduction in corruption, and improvement in logistics.

Kutin, Nguyen, and Vallée (2017) evaluated the efficiency of 50 ASEAN container ports to provide decision-making support to the terminal and port operators, thereby enhancing the transport network. They considered inland ports and seaports with different yard and quay equipment categories and performed the analysis using DEA CCR and DEA BCC models. Venkatasubbaiah, Rao, Rao, and Challa (2017) analysed the efficiency of 28 southeast Asian container terminals using a hybrid methodology by combining DEA and principal component analysis and arrived at a ranking of the container terminals (Venkatasubbaiah et al., 2017). More recently, Gil Ropero, Turias Domínguez, Jiménez, and del (2019) analysed the efficiency of container ports in Spain and Portugal with a two-stage method using DEA for the computation of efficiency and bootstrapping to determine the rankings. The technique of bootstrapping helped to test the hypothesis in the DEA models. Variation of 5% in technical efficiency is explained by the weather conditions for the Spanish container ports using frontier methods (García-Alonso, Moura, & Roibas, 2020). Shaheen and Elkalla (2019) carried out an efficiency analysis of Container ports of middle east using DEA CCR, BCC and found that 80% of the considered ports have shown increasing returns to scale. In the latest context, Seth and Feng (2020) adopted DEA models to calculate efficiency scores of 15 US container ports and benchmarked with the best ones.

Some researchers have criticised DEA and instead adopted a parametric method. López-Bermúdez, Freire-Seoane, and González-Laxe, (2019) in their research, adopted the stochastic frontier analysis (SFA) method to determine the efficiency of

20 Brazilian container terminals (López-Bermúdez et al., 2019). Wang and Han (2018) utilised Fuzzy DEA method to analyse 12 International container ports of Taiwan for different scenarios. Other researchers have used DEA CCR, DEA BCC and SFA in a combined fashion for scrutinizing the efficiency of container terminals (Kammoun & Abdenadher, 2018).

While evaluating the performance of the container terminals, it is imperative to consider the port and terminal characteristics (Caldeirinha, Felício, & Dionísio, 2013; Felício, Caldeirinha, & Dionísio, 2015). Within the scope of these studies, terminal infrastructure covers the following port elements: berth length, the length of the space where the vessel can park; quay crane, equipment to load and unload containers; draft, depth of the vessel bottom from the waterline; and yard infrastructure. In what is considered yard infrastructure, the following elements are often included in the analysis: container yard, the place where the containers are stored, handed over to agencies and collected from agencies; yard equipment, including the number of rubber tyre gantry cranes and rail-mounted gantry cranes for hoisting the containers; and reefer points, the number of slots for refrigerated containers which handle temperature-controlled shipments.

The list of input and output variables adopted by various researchers are captured in Table 1. Most researchers have adopted throughput as the output variable and length of quay, quay cranes and yard equipment as input variables. The variables considered in this study must cover the inputs under terminal infrastructure and yard infrastructure to measure efficiency in terms of throughput, which is the number of containers that a terminal can handle.

Research on usage of DEA for computing efficiency of Indian ports is captured in Table 2. Most of the researchers dealt with the major Indian ports and much less research is focused on the major and minor ports combined. Indian ports have moved their governance from the service model to the landlord model and couldn't improve the efficiency at all the ports significantly. There is a need for an optimal mix of governmental control and privatisation at the ports (Sinha & Roy Chowdhury, 2019).

Despite the vast research associated with the efficiency of container ports operating in major ports, there are no studies that focus on the micro-level, i.e. analysing the efficiency of all of the container terminals in India. Most of the researchers focused on computing the efficiency of the 13 major ports of India and neglected minor ports, which justifies the need to address the minor ports since they are consistently performing with an equal share of the throughput. Results from the analysis of ports as a whole, wherein bulk, containers and liquid cargo are transported, will leave us with a solution that cannot be implemented. Therefore, there is a need to compare container terminals rather than ports for a better investigation, which emphasises the importance of this study (Lu & Wang, 2017a). Some of the researchers (Sekar & Deo, 2012; Sekar, Ashraf, & Deo, 2014; Dasgupta & Sinha, 2016) who have analysed the efficiency of Indian ports have considered 2–3 inputs and 1–2 outputs for a sample of 13 major ports of India. This violates the requirement of the minimum sample size for DEA as stated in section 3.2. In this study, the number of inputs considered are 5 with throughput as output satisfying the requirement for DEA. This study adds to the literature as no such research has been carried out covering the entire list of container terminals of India.

## Research design

A production possibility frontier is constructed, and the DMUs are evaluated against the frontier. DEA models can be input oriented by minimising the inputs considered for a given output, or they can be output oriented by maximising the outputs for a fixed or given set of inputs. In addition to the above types, there are dif-

**Table 1**  
Variables considered by researchers for container ports' performance.

Researchers		Input		Output								
	Berth length/ Quay Length	Terminal Area	Total Refer Points	Total Quayside Cranes	Total Yard Equipment	Number of Berths	Draft	Size of Container Yard	Frequency of Calls	1/Turn Around Time per TEUs	Handling Trucks	Total Throughput
Munisamy and Singh (2011)	Y	Y	Y	Y	Y							Y
Niavis and Tsekeris (2012)	Y			Y		Y						Y
Almawsheki and Shah (2015)	Y	Y		Y	Y		Y					Y
Kutin et al. (2017)	Y			Y	Y		Y					Y
Venkatasubbaiah et al. (2017)	Y			Y	Y			Y				Y
Demirel et al. (2012)	Y	Y		Y	Y		Y					Y
López-Bermúdez et al. (2019)				Y	Y				Y			Y
Zheng and Park (2016)	Y			Y	Y			Y				Y
Lu and Wang (2017)	Y			Y	Y		Y	Y				Y
Choi (2011)	Y	Y		Y								Y
Dasgupta and Sinha (2016)				Y		Y	Y			Y		
Schøyen and Odeck (2013)	Y	Y		Y	Y						Y	Y

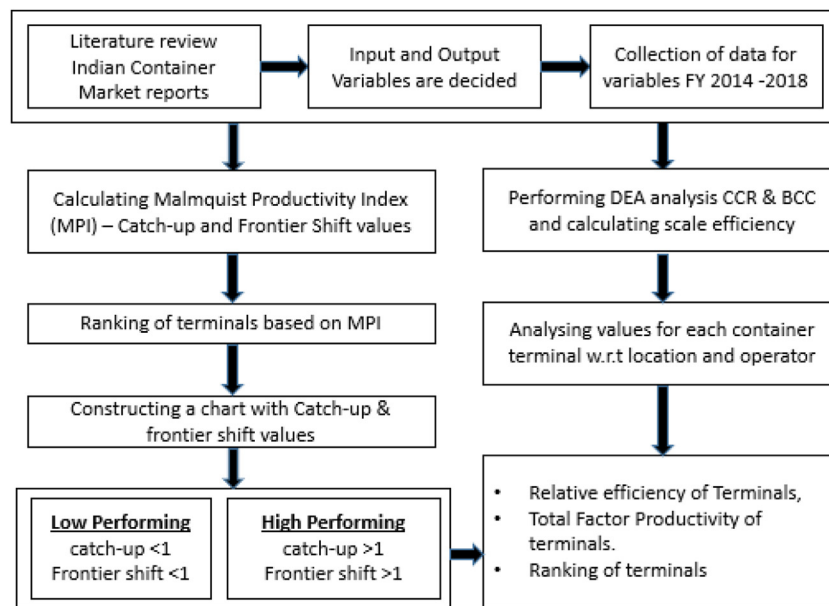
(Source: Authors)



**Table 2**  
Literature review on usage of DEA for efficiency of Indian Ports.

Author	Findings	Research Tool	Indian Ports
MONTEIRO (2018)	Indian ports have shown scale inefficiency for 7 years out of the 18 year periods	DEA–Malmquist	Total factor productivity analysis of major ports of India from 1998 to 2014
Dasgupta and Sinha (2016))	Effect of privatisation has significant effect on some ports	DEA	Impact of privatisation on container terminals of major ports of India
Sekar and Deo (2016)	There were no differences in efficiency based on input or output oriented	DEA	Efficiency analysis of minor ports of India
Sekar et al. (2014)	JNPT is the most efficient port and size influences the efficiency.	DEA–Super-efficiency	Efficiency analysis of major ports of India from 1993 to 2011
Sekar and Deo (2012)	Bigger ports as well as smaller ports had efficient operations	DEA Additive	Effect of size of the ports on the efficiency of major ports of India
Jim Wu and Lin (2008)	India's largest container port is not very efficient	Revealed Comparative Advantage & DEA	Effectiveness of logistics in comparison to global requirements and efficiency analysis of global container ports

(Source: Authors)



**Fig. 3.** Research methodology.

Source: Authors.

ferent variants of DEA, namely variable returns to scale (VRS) and constant returns to scale (CRS). CRS considers the scale of operation of a DMU as having no impact on its productivity, and VRS considers the opposite. In our study, it is intended to maximise the output using the available set of inputs; hence, an output-oriented model is considered here. The approach needed for achieving the objectives is shown in Fig. 3 and described in the next few paragraphs.

#### Identification of the inputs and outputs

Identification of the variables for analysis is the pivotal step in DEA. A review of the literature was conducted covering similar work, to identify the inputs and outputs needed for the efficiency analysis of the container terminals. Inputs and outputs for the DEA model were selected based on the consideration that output variables are a function of the input variables (Almawshaki & Shah, 2015), as shown in Eq. (1).

$$\text{Output(production)} = f(\text{Inputs}) = f(\text{land, labour, capital}) \quad (1)$$

Production is measured in terms of the number of containers handled, i.e. throughput. Land refers to natural resources, such as quay length, yard area, draft, etc. Labour refers to the time and

effort devoted by the human resources, and it is difficult to capture this data. Finally, capital refers to intermediate products, such as the equipment used in berth and yards. However, the majority of the researchers have excluded capital, owing to the sensitivity of the data (Almawshaki & Shah, 2015; Lu & Wang, 2017a). The input variables covered in the analysis include the physical characteristics of the terminal, such as terminal and yard infrastructure. The major consideration to be made while choosing the variables is the availability of data, as these correspond to terminals and not to the whole port. The majority of researchers have considered draft, quay length, terminal area and yard equipment as input variables, as presented in Table 1. The variables considered for our analysis are listed in Table 3. These are decided based on the recurring usage of variables in extensive literature, availability of data and to cover the concept of resources (input) split under land, labour and capital.

Information about the input and output variables of the 26 container terminals was collected from different official internet sources, such as the Ministry of Shipping's website (Ministry of Shipping (MoS), 2018), Indian container market reports (Behera, 2016, 2017, 2018) and the Indian Ports Association's website. Moreover, the panel data and cross-sectional data for multiple container terminals was collected for the years from 2014 to 2015

**Table 3**  
Variables considered for the model.

Category	Input Variables	Output Variable
Terminal Infrastructure Yard Infrastructure	Draft (m) Quay Length (m) Quay Cranes (No.) Yard equipment (No.) Yard Area (Ha)	Throughput in TEUs

(Source: Authors)

**Table 4**  
Summary Statistics of Variables.

Variables	(I)Draft (m)	(I)Quay Length (m)	(I)Yard Area (ha)	(I)Quay Cranes (No)	(I)Yard Equipment (No)	(O)Throughput (TEU)
Mean	13.83	614.09	22.98	5.45	20.18	615361.29
Min	8.5	250	4	2	2	21,018
Max	18	1460	90	15	51	2,027,896
Std. Deviation	2.22	201.57	16.41	3.00	12.73	494333.71

(Source: Authors)

to 2017–2018. Summary statistics of the considered variables are presented in Table 4.

#### Sample size and the duration for DEA

In this study, all 26 Indian container terminals are considered for study (i.e. 100% of the terminals) as shown in Appendix A; therefore, the chosen DMUs are homogeneous as they all handle only container cargo. Therefore, this study adheres to minimum sample size requirement with 26 terminals, 1 output and 5 inputs. The minimum sample size needed (N) for DEA (Lu & Wang, 2017b) is given below in Eq. (2).

$$N \geq \text{Maximum}\{\text{No.ofInputs} \times \text{No.ofOutputs}, 3(\text{No.ofInputs} + \text{No.ofOutputs})\} \quad (2)$$

The analysis considers the timeframe from 2014 to 2015 up to 2017–2018 for two main reasons. The first one concerns the availability of data for all of the container terminals operating in major and minor ports before 2014. The second one derives from the government of India having introduced the Sagarmala project in the year 2014–2015 to foster an integrated development of the coastline, demanding an increase in the performance of container ports and capacity expansion under an UNNATI project. It would be prudent to see the changes in efficiency during this period. Hence, we have analysed the changes in efficiency from 2014 to 2015 onwards (Ministry of Shipping (MoS), 2016).

outputs. Scale efficiency for each of the terminal is calculated with Eq. (3) (Niavis & Tsekeris, 2012).

$$\text{Scale Efficiency} = \frac{OTE}{PTE} \quad (3)$$

Scale efficiency denotes the appropriate size of the terminal to produce the output. It could be decreasing returns to scale, when variation of inputs is larger than the variation in outputs. It could be increasing returns to scale, when the variation of inputs is smaller than the variation in outputs. Any value of efficiency equal to 1 denotes a terminal that is efficient and lies on the production frontier. Any value of efficiency less than 1 denotes an inefficient terminal. If the scale efficiency of a terminal is less than its technical efficiency, then the terminal is scale inefficient and, vice versa, it is pure technical inefficient (Lu & Wang, 2017a).

#### Calculation of malmquist productivity index and ranking of terminals

Most of the researchers to date have looked at the efficiency aspect for DMUs and the frontier. There is a need to focus on shifts in the frontier technology, which is achieved through the Malmquist productivity index (MPI) (Bichou, 2018). This index indicates the growth of total factor productivity for the DMUs. It is calculated using Eqs (4) to 6.

$$\text{Catch} - \text{up} = \frac{\text{Efficiency of } (X, Y)^{2018} \text{ w.r.t frontier of 2018}}{\text{Efficiency of } (X, Y)^{2015} \text{ w.r.t frontier of 2015}} \quad (4)$$

$$\text{Frontier Shift} = \sqrt{\frac{(\text{Efficiency of } (X, Y)^{2015} \text{ w.r.t frontier of 2015})}{(\text{Efficiency of } (X, Y)^{2015} \text{ w.r.t frontier of 2018})} \times \frac{\text{Efficiency of } (X, Y)^{2018} \text{ w.r.t frontier of 2015}}{\text{Efficiency of } (X, Y)^{2018} \text{ w.r.t frontier of 2018}}} \quad (5)$$

where X and Y represent DMU.

$$\text{MPI} = \text{Catch} - \text{up} \times \text{Frontier Shift} \quad (6)$$

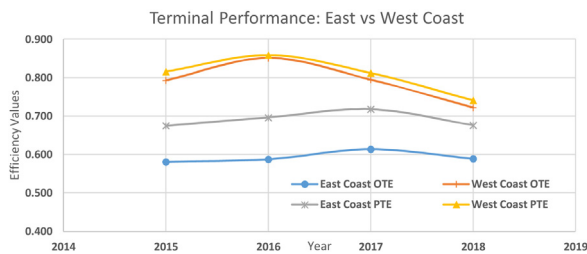
Based on the MPI scores, the container terminals are ranked. Container terminals are bifurcated into high-performing and low-performing terminals based on the break down of MPI into catch-up and frontier shift values. If both the values of catch-up and frontier shift are greater than 1, then the terminals are classified as high-performing terminals, else they are classified as low-performing terminals.

#### Results and discussion

The concepts of DEA CCR, DEA BCC, scale efficiency and Malmquist index were applied to 26 container terminals to arrive at the efficiency values, and subsequently ranking the same.

#### DEA model

Efficiency analysis using DEA CCR and BCC output-oriented models will be deployed for this study, and the analysis will be performed in the Microsoft Excel-based DEA Solver LV 8.0 from Springer. The DEA CCR model will give us the efficiency, which will be regarded as the overall technical efficiency (OTE) score for each terminal. The OTE of a terminal denotes the efficiency with which the terminal utilises inputs to produce outputs, comparing it to the best terminal. OTE is broken down into pure technical efficiency (PTE) and scale efficiency (SE) values for each terminal. The DEA BCC model gives us the PTE score for each terminal, and PTE captures the managerial performance in processing inputs to produce



**Fig. 4.** Efficiency of container terminals—East Coast vs West Coast.  
Source: Authors.

### Outcome of DEA

Results of the DEA analysis are presented in Table 5 with the average values indicated at the bottom. The average overall technical efficiency for Indian container terminals was 0.69 in the year 2014–2015, and it dropped down to 0.55 in 2017–2018. The average pure technical efficiency for Indian container terminals remained constant at 0.75 over three years before dropping down to 0.68 in 2017–2018. Average scale efficiency dropped from 0.93 to 0.85 in 4 years i.e. from 2015–2018. Indian container terminals must look at the scale of operations to improve efficiency. There is a need to dive further to understand whether the efficiency could be attributed to factors such as the port administration and control, location advantage, private sector participation or the size of the terminal. Efficiency values and the reasons for inefficiency for each terminal are presented in Table 5. In the year 2014–2015, there were 18 terminals in operation, out of which 6 terminals were efficient (33%), and 12 terminals (67%) were inefficient. Out of 12 terminals, 3 terminals (25%) need to focus on the operational aspects and improve managerial performance, and 9 terminals (75%) need to focus on the production scale.

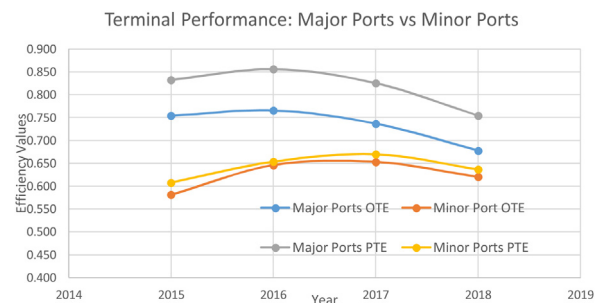
Referring to Table 5, we can infer that there are three terminals which are consistently efficient for four years, starting from 2014, and they are the APM Terminals Mumbai, the Bharat Kolkata container terminal and the PSA SICAL Tuticorin Container Terminal. If the terminal operators could document their best practices in these terminals, they could be implemented in other terminals.

A similar interpretation applies to other years, as provided in Table 6. It can be inferred from the analysis that the terminals became less efficient over the period of four years, and the majority of the terminals are experiencing scale inefficiency. It can be understood that determining the appropriate scale of operations should be focused on for the majority of these terminals.

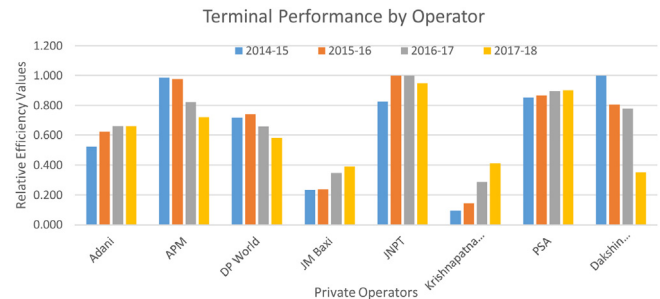
### Efficiency interpretations

The analysis was extended to understand the efficiency of container terminals on the east and west coasts. It is understood (refer to Fig. 4) that the container terminals on the west coast have higher levels of efficiency than container terminals along the east coast due to the presence of gigantic terminals such as the JNPT, the Adani terminals, the APM terminals and the Mundra terminals. The efficiency of container terminals on the west coast has seen an improvement of 1%, whereas the efficiency of terminals on the east coast is facing a decline. Heavy silting issues are prominent in east coast container terminals such as the Bharat Kolkata terminal and the Haldia International container terminal causing the decline. Terminals on the east coast must upgrade their infrastructure and increase their capacity to compete with the terminals on the west coast.

The slight increase in efficiency in the year 2016 for all of the container terminals is attributed to a project titled UNNATI by the



**Fig. 5.** Efficiency of container terminals in Major Ports vs Minor Ports.  
Source: Authors.



**Fig. 6.** Efficiency of container terminals by operator.  
Source: Authors.

Indian Ministry of Shipping, which consisted of 116 initiatives to improve operational and financial efficiency.

Container terminals operating in major ports have a different mechanism when compared to minor ports. Major ports' container terminals have higher levels of relative efficiencies when compared to terminals in minor ports due to the scale of operations. It can be inferred from Fig. 5 that the minor ports' container terminals showed an improvement of 7% in average efficiency in 2018 when compared against 2015. Container terminals in major ports have seen a decline of 10% in efficiency levels in 2018 compared against 2015 because they are facing constraints such as congestion at ports, high storage charges, being bound to a rate regime set by the Tariff Authority for Major Ports (TAMP), stiff competition from other terminals, etc. These concerns must be addressed to improve the efficiency of major ports. In addition, the terminals in major ports have to upgrade their infrastructure to continue benefitting from economies of scale.

Further, it is essential to analyse the efficiency of container terminals under different terminal operators. Terminals under Adani, JM Baxi, JNPT, Krishnapatnam and PSA operators have shown improvement, whereas other terminals run by APM, DP world and Dakshin Gateway have shown a decline in efficiency (Fig. 6). This improvement or decline is based on a comparison of 2018 efficiency to that of 2015. The reasons are attributed to the restriction on tariffs at major ports by TAMP, congestion and terminals attaining their optimum capacity. To take an example, DP World, has managed the Mundra International Container Terminal with consistent efficiency but has seen a decline in the efficiency for the Nhava Sheva International Container Limited terminal due to binding on tariffs at major ports.

Based on the efficiency values and throughput, it can also be inferred that the scale of operations is an essential determinant for terminal efficiency. This relationship can be understood by looking at the charts shown in Figs. 7 and 8. These charts depict that, the higher the throughput, the higher the efficiency of the container terminal. There are some outliers in the graphs which can



**Table 5**  
Efficiency Scores for Container Terminals (Source: Authors).

Year	2014–15				2015–16				2016–17				2017–18			
T No.	OTE	PTE	SE	Reason	OTE	PTE	SE	Reason	OTE	PTE	SE	Reason	OTE	PTE	SE	Reason
1	0.97	0.99	0.98	SIE	0.95	1.00	0.95	SIE	0.64	0.70	0.91	PTIE	0.44	0.44	1.00	PTIE
2	0.90	0.92	0.98	PTIE	0.93	0.93	1.00	PTIE	1.00	1.00	1.00		0.85	0.88	0.96	PTIE
3	1.00	1.00	1.00		1.00	1.00	1.00		0.85	0.89	0.96	PTIE	1.00	1.00	1.00	
4	0.82	0.97	0.85	SIE	1.00	1.00	1.00		1.00	1.00	1.00		0.72	0.78	0.94	PTIE
5	–	–	–		–	–	–		0.38	0.40	0.97	PTIE	0.71	0.73	0.98	PTIE
6	0.23	0.23	1.00	PTIE	0.38	0.38	1.00	PTIE	0.47	0.48	0.98	PTIE	0.50	0.52	0.95	PTIE
7	–	–	–		0.00	0.01	0.94	PTIE	–	–	–		0.16	0.17	0.95	PTIE
8	0.82	0.84	0.98	PTIE	1.00	1.00	1.00		1.00	1.00	1.00		0.95	0.98	0.97	SIE
9	1.00	1.00	1.00		0.88	0.89	0.99	PTIE	0.61	0.62	0.99	PTIE	0.48	0.51	0.94	PTIE
10					0.35	1.00	0.35	SIE	0.79	1.00	0.79	SIE	0.96	1.00	0.96	SIE
11	1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00	
12	–	–	–		–	–	–		–	–	–		0.01	0.01	0.96	PTIE
13	–	–	–		–	–	–		0.17	1.00	0.17	SIE	0.19	1.00	0.19	SIE
14	0.39	0.39	0.99	PTIE	0.51	0.52	0.98	PTIE	0.58	0.62	0.93	PTIE	0.56	0.56	0.99	PTIE
15	–	–	–		–	–	–		–	–	–		0.01	0.01	0.97	PTIE
16	0.97	0.97	1.00	PTIE	0.93	0.94	0.99	PTIE	0.61	0.65	0.95	PTIE	0.54	0.55	0.97	PTIE
17	0.55	0.62	0.89	PTIE	0.60	0.61	0.99	PTIE	0.69	0.69	1.00	PTIE	0.70	0.71	0.98	PTIE
18	–	–	–		–	–	–		–	–	–		0.21	1.00	0.21	SIE
19	0.33	0.33	0.99	PTIE	0.46	0.46	0.99	PTIE	0.48	0.50	0.97	PTIE	0.49	0.52	0.93	PTIE
20	0.10	0.10	0.92	PTIE	0.14	0.15	0.98	PTIE	0.29	0.29	0.98	PTIE	0.41	0.41	0.99	PTIE
21	0.05	0.05	0.99	PTIE	0.12	0.12	1.00	PTIE	0.33	0.33	1.00	PTIE	0.42	0.43	1.00	PTIE
22	1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00	
23	0.23	1.00	0.23	SIE	0.24	1.00	0.24	SIE	0.35	1.00	0.35	SIE	0.39	1.00	0.39	SIE
24	1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00	
25	1.00	1.00	1.00		0.81	1.00	0.81	SIE	0.78	1.00	0.78	SIE	0.35	0.46	0.77	PTIE
26	–	–	–		–	–	–		0.10	0.20	0.48	PTIE	0.15	1.00	0.15	SIE
<b>Average</b>	<b>0.69</b>	<b>0.75</b>	<b>0.93</b>		<b>0.67</b>	<b>0.75</b>	<b>0.91</b>		<b>0.64</b>	<b>0.74</b>	<b>0.87</b>		<b>0.55</b>	<b>0.68</b>	<b>0.85</b>	

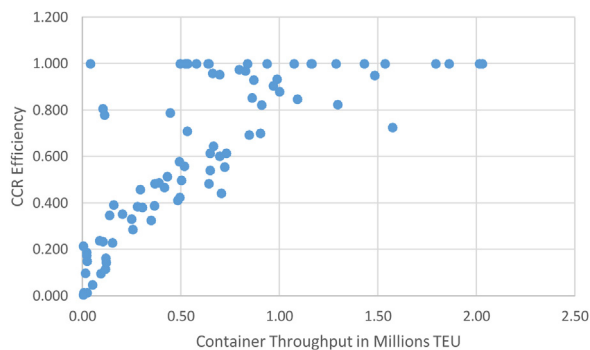
(Source: Authors)

Note: “SIE” in the table denotes “scale in efficiency” and “PTIE” denotes “pure technical inefficiency”.

**Table 6**  
Summary of Efficiency and Inefficiency Status.

Terminals Efficiency Status	2014–15	2015–16	2016–17	2017–18
Efficient	6 (33%)	6 (30%)	6 (27%)	4 (26%)
Inefficient	12 (67%)	14 (70%)	16 (73%)	22 (74%)
Pure technical Inefficient	3 (25%)	4 (29%)	4 (25%)	6 (27%)
Scale Inefficient	9 (75%)	10 (71%)	12 (75%)	16 (73%)

(Source: Authors)



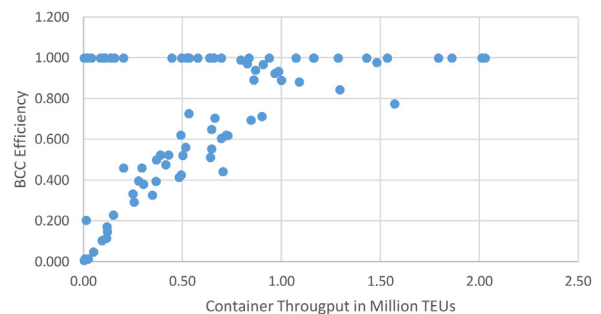
**Fig. 7.** CCR efficiency vs container throughput.

Source: Authors.

be ignored. Economies of scale are to be considered while planning the infrastructure requirements for container terminals.

Larger terminals can exploit the commercial, managerial, financial, technical and risk-bearing economies of scale. Hence, efficient utilisation of inputs against the outputs produced is more likely to happen. However, there is always a risk of falling into diseconomies of scale in the absence of efficient management and coordination.

CCR efficiency deals with the overall technical efficiency, assuming constant returns to scale, and BCC efficiency deals with the pure technical efficiency, assuming variable returns to scale. Container



**Fig. 8.** BCC efficiency vs container throughput.

Source: Authors.

terminals T22, T24 and T11 have their CCR efficiency and BCC efficiency equal to 1, which implies that these are operating at their productive level. Referring to Figs. 7 and 8, it could be inferred that the terminals above 0.9 million TEU are efficient, considering the scale of operations.

#### Malmquist productivity index

The Malmquist productivity index (MPI) helps us to understand productivity changes in the comparison of container terminals between 2014 and 2018. The MPI consists of two components,

**Table 7**  
Malmquist Productivity Index for Container Terminals.

Container Terminal	Catch-up	Frontier Shift	MPI	Rank
Kattupalli International Container Terminal	9.05	1.16	10.46	1
Krishnapatnam Port Container Terminal	4.30	1.02	4.39	2
Adani Hazira Container terminal	2.17	1.14	2.48	3
Vallarpadam International Container Transshipment Terminal	1.44	1.25	1.80	4
Visakha Container Terminal	1.47	1.12	1.64	5
Haldia International Container Terminal	1.67	0.86	1.44	6
Adani Mundra Container Terminal	1.00	1.30	1.30	7
Chennai International Terminal	1.26	0.99	1.25	8
PSA SICAL Tuticorin Container Terminal	1.00	1.24	1.24	9
Mundra International Container Terminal	0.94	1.19	1.11	10
Jawaharlal Nehru Port Container Terminal	1.11	1.00	1.10	11
APM Terminals Mumbai	1.00	0.93	0.93	12
Adani International Container Terminal	0.88	0.97	0.85	13
Bharat Kolkata Container Terminal	1.00	0.81	0.81	14
Chennai Container Terminal	0.56	1.32	0.74	15
APM Terminals Pipavav	0.45	1.24	0.56	16
Nhava Sheva International Container Terminal	0.48	1.14	0.55	17
Dakshin Bharat Gateway Terminal	0.35	0.55	0.19	18
<b>Average</b>	<b>1.67</b>	<b>1.07</b>	<b>1.82</b>	

(Source: Authors)

catch-up and frontier shift. Catch-up denotes the degree to which the container terminal progresses or regresses in its efficiency. The frontier shift reflects the shift in production frontiers between periods. In simple terms, catch-up refers to the recovery, and frontier shift refers to innovation. If catch-up is greater than 1, then it indicates an increase in the relative efficiency between periods. If catch-up is less than 1, then it indicates a decline in the relative efficiency between periods. If it is equal to 1, then there is no change. If the frontier shift is greater than 1, then it indicates progress in the frontier technology around the container terminal from 2014 to 2018, and if the frontier shift is less than 1, it indicates a decline in the frontier technology. If MPI is greater than 1, then it indicates progress in total factor productivity, and vice versa if the MPI less than 1. Referring to Table 7, 11 terminals have displayed an increase in total factor productivity from 2014 to 2018.

Despite being the most consistent terminals in terms of relative efficiency in the years 2015–2018, the total factor productivity growth of APM Terminals Mumbai and the Bharat Kolkata Container Terminal is less than 1 due to frontier shift regress. The only terminal which is consistent in terms of relative efficiency and total factor productivity growth over the years 2015–2018 is the PSA SICAL Tuticorin Container Terminal. This terminal could have registered higher values if it were free to set up its own tariffs and not abide by the TAMP. India's largest container terminal JNPT i.e. terminal 8 emerged to be an efficient terminal over the considered study period contradicting to work carried out by (Jim Wu & Lin, 2008) and the reason could be different study period in the studies. This confirms to the findings of research carried out by (Sekar et al., 2014).

A ranking of terminals is presented in Table 7, with the Kattupalli International Container Terminal being the first in terms of total factor productivity growth. The Kattupalli International Container Terminal has a capacity utilisation of 41%, which makes us understand that there is a lot of room for improvement through attaining optimum capacity utilisation. This is also the case for the Krishnapatnam Port Container Terminal, which has a capacity utilisation of 40%. This achievement is attributed to advanced infrastructure and improvements in hinterland connectivity. The Adani Hazira Container Terminal, which ranks in third place, benefits from its strategic location, excellent multimodal connectivity and good infrastructure. Any improvement in the efficiency of this terminal will lead to substantial savings in the cost of logistics.

To bifurcate the terminals into low-performing and high-performing categories, their catch up and frontier shift values were

considered. High-performing terminals are categorised as those where catch-up and frontier shift values are greater than 1. Low-performing terminals are those where these values are less than 1. The Kattupalli International Container Terminal and the Krishnapatnam Port Container Terminal are not shown in Fig. 9 to have a clear representation of other terminals on the graph. The high performing terminals, as identified, are the Kattupalli International Container Terminal, the Krishnapatnam Port Container Terminal, the Adani Mundra Container Terminal, the Adani Hazira Container Terminal, the Vallarpadam International Container Transshipment Terminal, the Visakha Container Terminal and the PSA SICAL Tuticorin Container Terminal. The low performing terminals are the Dakshin Bharat Gateway Terminal and the Adani International Container Terminal. The rest of the container terminals must improve either their catch-up values or frontier shift values.

## Discussion

The initial findings from the study include that the overall average technical efficiency of container ports was declining from 0.69 in 2015 to 0.55 in 2018. The average pure technical efficiency was declining from 0.75 in 2015 to 0.68 in 2018, which indicates that there is a 32% level of technical inefficiency in the container terminals of India. The average scale efficiency is declining from 0.93 in 2015 to 0.85 in 2018, which indicates that there is a 15% level of scale inefficiency in the container terminals of India. It can be inferred from Table 4, that there has been an increasing number of scale-inefficient container terminals in India for over the period of 4 years. The majority of container terminals are operating at the wrong scale of operations, and terminals with a higher scale of operations proved to be more efficient, which corroborates with the findings of the researchers Sekar et al. (2014), Sekar & Deo (2012), and Almawshaki & Shah (2015). The average efficiency is declining rapidly for east coast terminals when compared to those on the west coast. The reasons attributed to this observation are the heavy silting problems, inadequate infrastructure, hinterland connectivity, etc.

From a governance and control perspective, container terminals under minor ports are progressing, and container terminals under major ports are regressing, owing to tariff issues with TAMP and high logistics costs. There is a notion that private players can bring improved performance with the modernisation and upgrading of infrastructure. In this research, there are some private players such as APM, DP world and Dakshin Gateway who have shown a decline

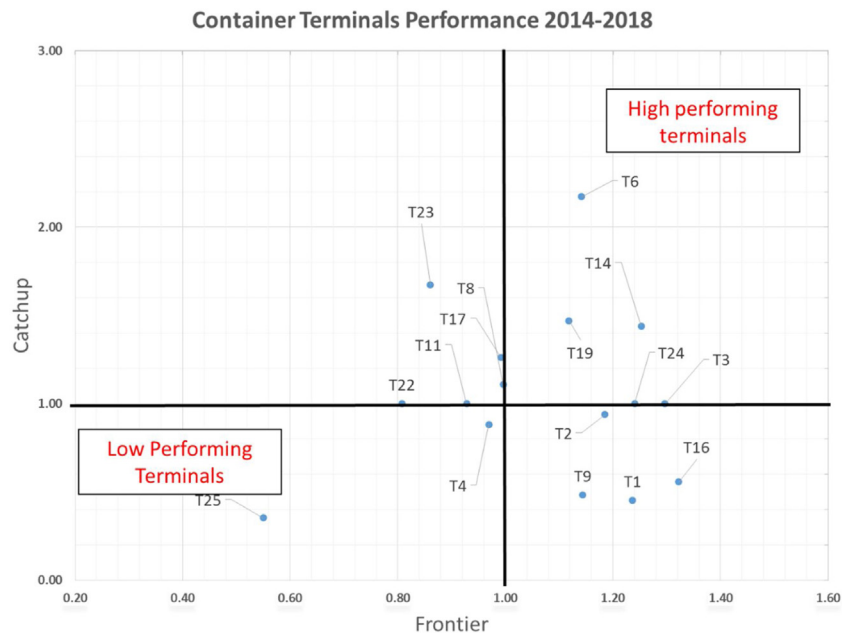


Fig. 9. Classification of other container terminals.

Source: Authors.

in their efficiency over four years. These operators run terminals that have higher throughputs of up to 2 million TEUs. Based on the analysis, it can be understood that the private operators have influenced the efficiency of container terminals such as T20, T21 and T15 to a great extent, but this finding does not apply to all cases (such as T1 and T9) and is in line with findings by Dasgupta & Sinha (2016) and Demirel et al. (2012).

The ranking of terminals was presented based on the Malmquist index for 18 terminals. Eight terminals were not completely operational during the past four years. Seven terminals fell into the high-performing category and two into the low-performing category. Economies of scale play a key role in the efficiency of container terminals. The PSA SICAL Tuticorin Container Terminal emerged to be the most consistent terminal, in terms of relative efficiency as well as growth in total factor productivity from 2014 to 2018. Identifying the reasons for inefficiency in each of the container terminals helps terminal operators plan the necessary mitigation measures in order to improve their growth. The ranking of the container terminals also enables terminal operators to adopt best practices derived from high-performing terminals. Greater efficiency would enhance the profitability of container terminals. The findings in this study shall help the port managers to identify the sources of inefficiency as managerial cum technological or scale related for each of the terminals. These could help the managers to decide upon the demand and supply mismatches for the throughput.

## Conclusion

The goal of this research was to analyse the efficiency of the container terminals of India and to rank and bifurcate them into high-performing and low-performing terminals. Efficiency analysis included the calculation of relative efficiency using DEA CCR and DEA BCC models, the calculation of the Malmquist productiv-

ity index, and the interpretation of efficiency levels for east and west coast terminals, terminals in major and minor ports and terminals run by different operators. This research has produced insights into all of the container terminals of India, along with their reasons for inefficiency. There are numerous challenges associated with the container terminals of India. The development of container terminals in the vicinity of others will deprive the existing terminals, ultimately leading to the underutilisation of existing assets. The findings recommend that the managers of ports should consider improving the efficiency of existing terminals, improving the scale of operations rather than setting up new terminals, as the existing terminals are to be exploited to the economies of scale.

This research has limitations concerning the considerations of time and inputs. Other inputs, such as labour, could be accommodated in this study to understand their influence. The effect of qualitative factors, such as unstable conditions, government reforms, hinterland connectivity, management, etc. could also be explored. The future scope could include a detailed analysis of each container terminal's enabling and inhibiting factors that could impact its operational and financial efficiencies. Models could be created to understand the quantitative impact of these factors on the efficiency of container ports. This study can be extended to understand the profitability and sustainability of container terminals when the required input variable data and output variable data are available.

**Appendix A. List of container terminals present in India along with the location whether in east coast or west coast, whether they are controlled by major ports or minor ports and the governance model of each of the terminal is presented in the below table**

Terminal No.	Name of the Terminal	Located in	Operated under	Port model	Terminal Operator
1	APM Terminals Pipavav	West Coast	Minor port	Private Port	• APM Terminals Pipavav
2	Mundra International Container Terminal	West Coast	Minor port	Private Port	• DP World
3	Adani Mundra Container Terminal	West Coast	Minor port	Private Port	• Adani Ports & SEZ Ltd
4	Adani International Container Terminal	West Coast	Minor port	Private Port	• JV of Adani Ports and • SEZ Ltd and MSC
5	Adani CMA Mundra Terminal	West Coast	Minor port	Private Port	• JV of APSEZ and • CMA CGM SA
6	Adani Hazira Container terminal	West Coast	Minor port	Private Port	• Adani Ports & SEZ Ltd
7	Kandla International Container Terminal	West Coast	Major port	Landlord Port	• ICTIPL • JM Baxi Group
8	Jawaharlal Nehru Port Container Terminal	West Coast	Major port	Landlord Port	• Jawaharlal Nehru Port Trust
9	Nhava Sheva International Container Terminal	West Coast	Major port	Landlord Port	• DP World
10	Nhava Sheva India Gateway Terminal	West Coast	Major port	Landlord Port	• DP World
11	APM Terminals Mumbai	West Coast	Major port	Landlord Port	• APM Terminals CONCOR
12	Bharat Mumbai Container Terminals	West Coast	Major port	Landlord Port	• PSA International
13	Mormugao Port	West Coast	Major port	Public Service Port	• Mormugao Port Trust
14	Vallarpadam International Container Transshipment Terminal	West Coast	Major port	Landlord Port	• DP World
15	Paradip Port	East Coast	Major port	Landlord Port	• ICTIPL - JM Baxi
16	Chennai Container Terminal	East Coast	Major port	Landlord Port	• DP World
17	Chennai International Terminal	East Coast	Major port	Landlord Port	• PSA Chennai
18	Adani Ennore Container Terminal	East Coast	Major port	Landlord Port	• Adani Ports • SEZ Ltd
19	Visakha Container Terminal	East Coast	Major port	Landlord Port	• ICTIPL • DP World
20	Krishnapatnam Port Container Terminal	East Coast	Minor port	Private Port	• KPCT
21	Katupalli International Container Terminal	East Coast	Minor port	Private Port	• Adani Ports & SEZ Ltd
22	Bharat Kolkata Container Terminal	East Coast	Major port	Landlord Port	• PSA International (Provides only O&M services)
23	Haldia International Container Terminal	East Coast	Major port	Landlord Port	• ICTIPL - JM Baxi
24	PSA SICAL Tuticorin Container Terminal	East Coast	Major port	Landlord Port	• Sical and PSA International
25	Dakshin Bharat Gateway Terminal	East Coast	Major port	Landlord Port	• Dakshin Bharat Gateway Terminal Pvt Ltd
26	PSA - Kakinada Container Terminal	East Coast	Minor port	Private Port	• Bothra Shipping, • Kakinada Infrastructure Holdings • PSA Chennai Invest-ments

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