

Evaluating The Effectiveness Of Indian Container Terminals: Data Envelopment Analysis

Ennarasu Karunesan¹, Dr.B. Swaminathan²

¹Doctoral Research Scholar, Indian Maritime
University- Chennai.

²Associate Professor at School of Maritime Management,
Indian Maritime University- Chennai Campus.

ABSTRACT:

The total cargo volume for international maritime trade rebounded to 11.0 billion tons in 2021. In the maritime industry, container transport is an efficient and well-established mode of transportation. The container industry has grown faster than any other mode of cargo transportation over the past two decades, with 820 million TEUs handled annually across all ports. In the context of large ships with a capacity of 24,000 TEUs, it has become increasingly important for container ports and terminals to benchmark their efficiency, which has become an urgent requirement as ports and terminals become more complex. In other words, over the past few decades, global trade has grown exponentially, leading to a worldwide surge in container terminal operations. In the global trade scenario, India's container terminal efficiency is becoming increasingly important as one of the fastest-growing economies. Due to the above background, the effectiveness of Indian container ports is assessed in this article using Data Envelopment Analysis. In analysing the data, this article provides insights that can help improve the long-term efficiency of these terminals by shedding light on their strengths and weaknesses.

Key Words: Data envelopment analysis, Decision-making units, Twenty Foot Equivalent Unit.

1.Introduction

Ports serve as logistical platforms for receiving and transferring cargo between hinterland locations and are the gateways to domestic and international trade. Maritime transport account for 70% of the value of Indian trade, with Indian ports handling approximately 90% of its trade volume (Maritime India Vision 2030)^[1]. According to Basic Port Statistics of India, 2021-2022, all major and non-major ports handled 1319 million metric tons of cargo during the financial year 2021-22, including 20% of containerized cargo^[2]. Global container port traffic handled by Indian

container terminals in 2021 was 2% (UNCTAD Review of Maritime Transport 2021)^[3].

Since 2003, the Jawaharlal Nehru Port Trust has routinely ranked among the globally top 30 container ports in terms of throughput (Nightingale, 2018; Paul, 2005)^[4].

It is anticipated that global maritime trade will expand by 1.4% in 2022, 2.1% in 2023-2027, and then at a slower rate than the 3.3% average growth rate during the previous three decades. Currently, containerized trade represents the fastest-growing segment, with growth of 1.2% in 2022 and 1.9% in 2023.^[5]

According to statistics from the International Maritime Organization, 42% of exports and 64% of imports were handled in Asia in 2021. On the main East-West routes, around 40% of containerized trade was between Asia, Europe, and the United States in 2021. South Asia-Mediterranean is one of the non-main lane East-West routes that accounted for 12.9 per cent.

Depending on the trade direction, container shipping lines performed differently. There was a 15% increase in transpacific volumes, primarily due to a 20% increase in East Asia to North America. The Asia-Europe route experienced a 10 per cent increase in trade, supported by a 14.7 per cent increase in East-Asia-to-Europe trade. Almost half of the container traffic was exported by Asian countries in 2021, including the Republic of Korea, Vietnam, China, and Japan^[5].

As containerized cargo demand surged, world maritime trade rebounded in 2021. The number of shipments increased by 3.2% to reach 11 billion tons. By comparison, in 2020 there was a decline of 3.8%, an improvement of 7 percentage points. The UNCTAD predicts that maritime trade will lose steam in 2022 as growth slows to 1.4%. Its growth rate is expected to slow to 2.1% annually from 2023 to 2027, compared with the average of 3.3% during the previous three decades.^[6]

Capacity is optimally utilized, alliances and industry consolidation are becoming increasingly important, and supply and demand mismatches are leading to reduced freight rates (Kourounioti, Polydoropoulou, & Tsiklidis, 2016)^[7]. As a result, for Indian container ports to become more efficient, they must upgrade infrastructure, address connectivity issues, and accommodate larger vessels (Kourounioti, Polydoropoulou, & Tsiklidis, 2016)^[7].

Additionally, the Ministry of Ports, Shipping, and Waterways (MoPSW) established Sagarmala program in 2015 with the intention of increasing container traffic to 25 million TEUs over 2025 (Sagarmala, Ministry of Sh

ipping (MoS) 2016). ^[8]. As a matter of fact, there is no doubt that container terminals will have to improve their efficiency and capacity in order to meet the rapidly increasing demand for containerized shipping. The efficiency of a port is influenced not only by the amount of time ships spend in ports but also by cargo handling, hinterland connectivity, and the superstructure and infrastructure of the port.

2. Review of literature

Container terminals are essential components of the global supply chain network as they facilitate the transporting products between modes of conveyance, such as ships, trains, and trucks and trailers. Terminal efficiency is critical for optimizing terminal resource utilisation and maximising supply chain productivity. This literature review provides an overview of the different parameters affecting global container terminals' efficiency.

The CCR abbreviation refers for Charnes, Cooper, and Rhodes, who established Data Envelopment Analysis in 1978 as a refinement of Farrell's (1957) method [9] to compare the efficacy of units that make decisions utilizing both a multi-input multi-output mode and a multi-input single-output mode.

In the CCR article, a sequential processing approach is used to weigh a set of units that make choices and quantify their efficiency.

De Monie (1995)^[10] assessed of Indian port performance led to the conclusion that administrative concerns had contributed to low performance. The pressing needs of Indian ports have been identified as equipment modernization, privatization, and institutional reforms. De and Ghosh (2003) ^[11] investigated the causal link between traffic and performance. Their findings suggest that port operation could be enhanced via carefully balancing productivity, turnover time, and berth capacity.

Similarly, in their study, Rathi et al. (2012) ^[12] identified the criteria critical to determining operational efficiency in any of the port and analyzed those characteristics for Jawaharlal Nehru Port Trust's container port to offer strategies to enhance it. Essential metrics such as container turnaround time, cargo dwell time, passage time, monetary indicators, personnel indicators, and so on were discovered in their analysis for each container port. Rajasekar and Deo ^[13] found berth throughput, operational expenses, and personnel quantity as positive predictors of port performance, as negative variables such as cargo equipment breakdown and idle time. Outside forces such as NSDP in agriculture, manufacturing, have little effect on port performance.

Venkatasubbaiah et al. (2017) ^[14] DEA was used to analyse the effect of terminal features such as quay length & crane, yard area and cranes on container port performance. It was observed that these characteristics have distinct and combined effects which affect container terminal performance.

In assessing the performance of container terminals, it is important to take into account the port's and terminal's characteristics. (Caldeirinha Felcio, & Dionisio, 2013 & 2015) ^[15]. Container throughput is the primary performance indicator for container terminals. It refers to the number of containers the terminal handles in a given period, say annually. Terminal efficiency is directly proportional to container throughput. Terminals strive to increase throughput by reducing container dwell time, improving equipment utilization, and optimizing yard and vessel operations. Terminal productivity measures the efficiency of terminal resources, such as container handling equipment, terminal equipment operators, operations planning & execution staff and space utilization. Efficient use of terminal resources can improve productivity and reduce operational costs. Terminal operators aim to increase productivity by adopting advanced technologies, improving operational processes, and optimizing resource allocation.

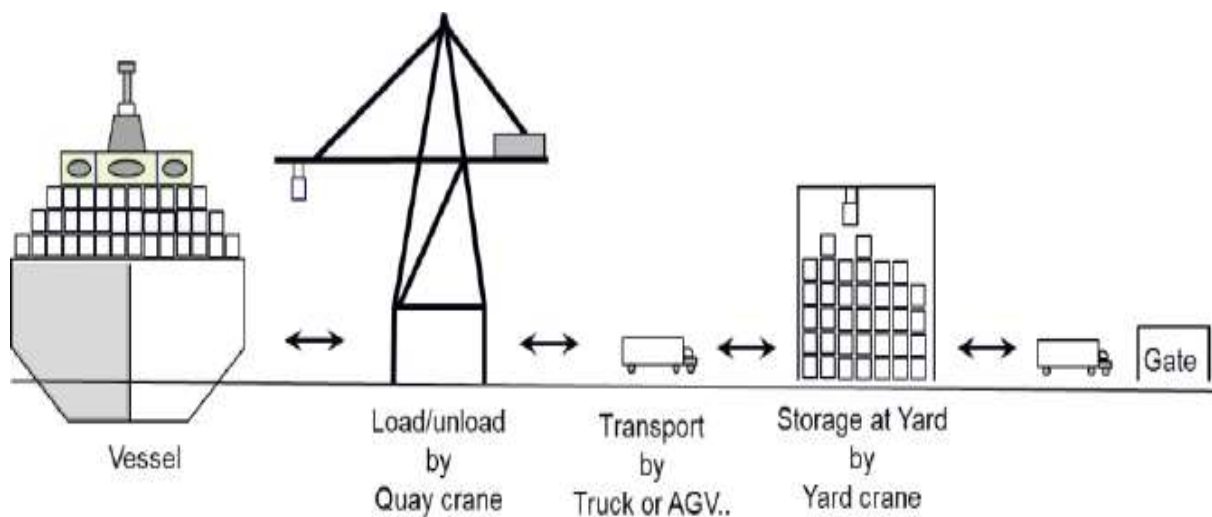
Turnaround time refers to the time a vessel unloads and loads containers at a terminal. In other words, a vessel's turnaround time begins after it arrives at the port and ends after it leaves. It is the total amount of time between arrival and departure that counts towards turnaround time. It is a crucial parameter affecting vessel productivity and the terminal's throughput. Improving vessel productivity (higher Crane Productivity) leads to speedy vessel turnaround time and thus increases the terminal throughput. Ship Productivity is one of the ships performance indicators, which is calculated by dividing total number of containers handled to and from the vessel by the ship's stay time at berth. Berth productivity measures the efficiency of terminal vessel handling operations. It is calculated by dividing the number of containers the terminal handles by the vessel's time at berth. Efficient berthing and sailing operations can improve vessel productivity, better utilisation of terminal resources and faster the vessel turnaround time.

Equipment utilization is when terminal equipment, such as cranes, trucks and trailers deployed. Efficient equipment utilization can reduce operational costs and increase terminal productivity. Terminal operators can improve equipment utilization by reducing idle time due to majorly due to break-down, improving maintenance practices, and optimizing equipment deployment. Yard utilization measures the efficiency of terminal storage operations. A yard's capacity is determined by dividing the number of containers stacked in it by its total capacity. The efficiency

of yard operations can increase terminal productivity and reduce dwell time for containers.

The dwell time of a container refers to how long it stays at a terminal before it is shipped out. Reducing container dwell time can improve terminal efficiency by increasing container throughput and reducing operational costs. Labour productivity measures the efficiency of the terminal's labour force such as equipment operators, planning and operations staff engaged for handling the vessel. It is calculated by dividing the number of containers the terminal handles by the labour hours worked. Efficient labour utilization can reduce operational costs and increase terminal productivity.

Figure 1 : Shows Container Terminal Operation



Many studies on container terminal efficiency focus on developed nations, such as the U.S., whereas only a few are focused on developing countries, such as India. As India is poised to become third largest economies of the world in a decade's time with a five trillion-dollar economy in next few years. As the Port's in India plays an important role in the transshipment process as a result of its location advantage. As a result, better understanding the functioning of such ports at micro level, especially at terminus level sooner than the port level, is required.

In conclusion, the literature review on container terminal efficiency shows that various factors affect terminal performance. Among them are technology, infrastructure, management, and government policies. Container terminals need to adopt innovative technologies such as Big Data (BD), Machine Learning (ML), Artificial Intelligence (AI), use of Internet of Things (IoT), Block Chain (BC), Optical Character

Recognition(OCR), implement efficient management practices, and invest in infrastructure. A government policy that supports trade and investment in the container terminal industry can also improve efficiency. In summary, the literature indicates that container terminal efficiency is a complex issue involving multiple factors which require a holistic approach.

3. Methodology

The research investigates the operational effectiveness of 15 container ports in India that have been in operation for more than ten years using a DEA for the fiscal year 2022-23. The study investigates the productivity of terminal operations based on three factors: location benefit, administrative oversight, and private control. The variables of DEA analysis, such as inputs as well as outcomes, will be discussed. In the analysis, the authors use a DEA model (CCR or BCC) to describe the assumptions underlying the DEA model. The DEA analysis results, including efficiency scores and rankings for 15 container terminals, will be provided with a detailed explanation of the DEA analysis steps. This paper interprets the results, discusses their implications for the Indian container terminal industry, and identifies the strengths and weaknesses of the DEA analysis.

The research also aims to measure productivity changes over time by deconstructing the Malmquist index into catch-up efficiency changes and frontier shifts. The study assesses container ports based on competence and concludes that terminals on India's west coast outperform those on the eastern coastline. The investigators suggest that the DEA and Malmquist of Fifteen container terminals would be a modest start of analysis to estimate the terminal's efficiency in the current circumstances.

4. Malmquist Productivity Index

Malmquist Productivity Index (MPI) is a distance function introduced by (Caves in 1982) ^[20]. Based on an input vector and production technology, Malmquist TFP index calculates the maximum outputs possible. It measures the radial distance between the experiential output vectors and reference technology. The Malmquist productivity index for t is represented by Equation

$$M^t = \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \dots\dots\dots(1)$$

Accordingly, it is demarcated as the ratio of two output distance functions relative to position technology. Another productivity index can also be constructed by using period t+1's technology as the reference technology, as follows:

$$M^{t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \dots\dots\dots (2)$$

The MPI is defined as the geometric mean of the two period indices, which eliminates the arbitrariness in the choice of the benchmark technology depending on the time period t or t+1

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) =$$

$$\left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \right) \left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \right) \right]^{\frac{1}{2}}$$

Inputs and outputs are represented by x and y, distance D₀ is the distance, and Malmquist index M is the Malmquist index. Mathematical manipulations have shown that MPI is composed of two distinct components, viz technical change and efficiency change:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t)$$

Where,

$$\text{Efficiency change} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \dots\dots\dots (5)$$

And,

$$\left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right) \right]$$

Technical change =

DEA constructs a piecewise linear frontier based on the distribution of inputs and outputs from various entities/decision-making units (DMUs). The production frontier constructs a piecewise surface such that the observed data lies on or below it (Coelli et al., 2005). This production frontier determines the efficiency measure for each DMU. According to Fare et al. (1994), the Malmquist Productivity Index has four important advantages.

They include:

- a. In many countries, prices are not available for every input and output;
- b. Since linear programming does not assume an underlying production function, the error term does not have stochastic properties;
- c. There is no prior assumption about DMU optimization

- d. Using the approach, it is possible to decay the Total Factor Productivity TFP into its technical change and efficiency change components

5. Identification of the inputs and outputs

As part of DEA process, inputs and outputs are identified, and their efficiency is assessed. DEA models use inputs and outputs since output variables depend on input variables. An optimization technique known as DEA is widely used to evaluate the relative efficiency of DMUs. The method analyses the inputs and outputs of each DMU to determine efficiency. An important step in the DEA analysis is identifying the inputs and outputs since it allows different DMUs to be compared. Among DMU's inputs are the resources it consumes, while among its outputs are results. Decision-makers can use DEA in many fields, including finance, operations management, and healthcare.

Table 1.0 : Major Indian Container Terminals FY 2022-23
Infrastructure facilities of various Container Terminals

S.No.	Container Terminals	Quay Length (in meter)	Quay Crane/ MHC (Nos)	Yard Area (in hectares)	RTG / RS (Nos)	Tractor Trailer s (Nos)	Container Throughput (FY 2022-23) TEUs
1	APM Terminals Pipavav	735	8	36	29	56	763980
2	MICT- DP World, Mundra	632	7	25	24	46	1121351
3	AMCT – Adani Ports, Mundra	631	6	19.47	24	42	1051358
4	AICT – JV (Adani & MSC), Mundra	1460	17	67	54	110	2861044
5	JNPCT, Nhava Sheva	680	6	62	27	40	255584
6	NSICT – DP World, Nhava Sheva	600	8	26	32	56	1096953
7	APM Terminals Mumbai	712	10	30	42	70	1838036
8	NMPT -Mangalore JSW	350	2*	6.6	7	18	165546
9	Vallarpadam-DP World, Cochin	600	4+2*	61	18	30	695212
10	PSA SICAL, Tuticorin	370	3	10	10	22	164575
11	CCTL- DP World, Chennai	885	7	18	23	42	654579

12	CITPL- PSA, Chennai	832	7	28	21	55	810433
13	KICT – Adani Ports, Kattupalli	710	7	18	20	45	685623
14	NCT – Adani Krishnapatnam	650	4+1**	36	16	30	99775
15	VCTPL- JM Baxi, Vizag	850	7	20	24	43	528121

Source: Administrative Reports of Select Container Terminals 2022-23

MHC- Mobile Harbour Crane : RTG- Rubber Tyred Gantry Crane : RS- Reach Stacker

* Mobile Harbour Crane

** QC Moved to Adani Kattupalli CT during Jan 2023.

The DEA Efficiency scores in this study is estimated using the computer programme Solver Analysis. In this study it is found that DEA model run in this study is under the assumption of scale efficiency. Table 1.0 shows that the data collected from primary sources given as input and output archived by several Indian Ports. Where Adani International Container Terminal (AICT) at Mundra handled the highest number of containers (**2861044 TEUs**) in the period FY 2022-23.

The following table represent the resource utilization performance of 15 container terminals. The terminals are identified by numbers 1 to 15, and four performance measures are used to evaluate them: Constant Returns Scale Technical Efficiency, Variable Returns to Scale Technical Efficiency, Scale Technical Efficiency, and Overall Technical Efficiency or Input-Output Ratio Scale. The performance of these firms can be analyzed by examining the mean values of the performance measures. As a result, the mean CRSTE, VRSTE, SCALE, and IRS are 0.658, 0.852, 0.75 and IRS, respectively.

The mean values indicate that, on average, container terminals are relatively efficient in cost and revenue. Furthermore, they exhibit high scale and technical efficiency levels, demonstrating efficient use of resources to produce goods and services. For example, Adani International Container Terminal, Mundra and APM Terminals, Mumbai achieves an average score of 1.000 for all performance measures, indicating a highly efficient use of resources. In contrast, Adani Krishnapatnam Container Terminal has relatively low scores for all performance measures, indicating that it may need to improve its resource utilization to become more efficient. Overall, the data provided provides insight into the resource utilization performance of the 15 container terminals. However, further analysis may be required to determine the underlying factors contributing to their performance and identify improvement areas.

Table 2.0: Outputs of Container Terminal Scale Efficiency

S.No.	Container Terminal	CRSTE	VRSTE	Scale Efficiency	Return to Scale
1	APM Terminals Pipavav	0.545	0.663	0.823	irs
2	MICT- DP World, Mundra	0.944	1	0.944	irs
3	AMCT – Adani Ports, Mundra	0.969	1	0.969	irs
4	AICT – JV (Adani & MSC), Mundra	1	1	1	-
5	JNPCT, Nhava Sheva	0.243	0.543	0.448	irs
6	NSICT – DP World, Nhava Sheva	0.759	0.919	0.825	irs
7	APM Terminals Mumbai	1	1	1	-
8	NMPT - JSW	0.495	1	0.495	irs
9	Vallarpadam-DP World, Cochin	0.883	1	0.883	irs
10	PSA SICAL, Tuticorin	0.337	0.946	0.357	irs
11	CCTL- DP World, Chennai	0.633	0.757	0.836	irs
12	CITPL- PSA, Chennai	0.728	0.869	0.838	irs
13	KICT – Adani Ports, Kattupalli	0.729	0.836	0.872	irs
14	NCT – Adani Krishnapatnam	0.127	0.6	0.212	irs
15	VCTPL- JM Baxi, Vizag	0.48	0.646	0.743	irs
Mean		0.658	0.852	0.75	

Source: Computed

Note: Crste = technical efficiency from CRS DEA; Vrste = technical efficiency from VRS DEA; Scale = scale efficiency = Crste/ Vrste

In Table 2.0, the right-most column shows the Return to Scale of each terminal determined by DEA scores. As of this analysis, AICT - JV (Adani & MSC), Mundra and APM Terminals Mumbai shows 100% technical efficiency in both CRS and VRS, and all other terminals showed IRS. The Port performance is described by increasing, decreasing, and constant returns to scale (IRS, DRS, CRS) as economic concepts that characterize the relationship between inputs and outputs. From the table 2.0 shows that one of the terminals Adani Krishnapatnam Terminal shows 21% overall scale efficiency during FY 2022-23, has an output of 99,775 TEUs (Table 1.0). It means that this terminal has the ability to maximise its output at an increasing rate proportionately. Hence it has an increasing return to scale.

The IRS indicates that the terminal's scale is less than its operational capacity. Despite having the resources to handle it, the terminals are not efficient enough to handle its actual capacity, which implies that the terminal should be enhanced by expanding terminals and operational capabilities. When an increase in inputs leads to a proportional increase in the outputs, as in the case of Adani International Container Terminal,

Mundra and APM Terminal, Mumbai with more than 1.5 million TEUs annually. In other words, as the terminal scales up, its efficiency remains constant, resulting in the same cost per unit of output or CRS. It is not possible to increase the quality of the product through scale, but it can be achieved and enhanced through technological advances.

6. Container Terminal Ranking

There are a number of container terminals listed in the table along with their scale efficiency rankings and scores. A terminal's scale efficiency is a measure of how efficiently resources are used to produce its output. As indicated by the scores listed, each terminal has achieved a percentage of its maximum possible efficiency.

Table 3.0 : Indian Container Terminals Rank by Using DEA Analysis

Container Terminals	Rank	Scale Efficiency (%)
AICT – JV (Adani & MSC), Mundra	1	100%
APM Terminals Mumbai	1	100%
AMCT – Adani Ports, Mundra	2	97%
MICT- DP World, Mundra	3	94%
Vallarpadam-DP World, Cochin	4	88%
KICT – Adani Ports, Kattupalli	5	87%
CITPL- PSA, Chennai	6	84%
CCTL- DP World, Chennai	7	84%
NSICT – DP World, Nhava Sheva	8	83%
APM Terminals Pipavav	9	82%
VCTPL- JM Baxi, Vizag	10	74%
NMPT -Mangalore JSW	11	50%
JNPCT, Nhava Sheva	12	45%
PSA SICAL, Tuticorin	13	36%
NCT – Adani Krishnapatnam	14	21%

Source: Computed using DEA Analysis

In the table, AICTPL – JV (Adani & MSC), Mundra and APM Terminals Mumbai ranks first with a score of 100% for scale efficiency. Adani Ports Mundra Container Terminal (AMCT) and MICT-DP World follow closely with scores of 97% and 94 %, respectively. With a score of 21 %, NCT-Krishnapatnam Port is the least efficient terminal on the list.

7. Conclusion and suggestions

In light of globalisation and competition, port performance is crucial for port competitiveness. By using DEA, this study evaluated the efficiency and scale of 15 container terminals in India that have been operating for more than decade. It is common for container terminals to experience

both pure and scale inefficiency. The problem can be addressed by improving management practices and upgrading technology. Inefficiency caused by scale, however, results from increased operations. A container terminal may experience bottlenecks in cargo handling as cargo volumes increase due to limited infrastructure and equipment. Insufficient cranes at a container terminal, for example, may cause ships to wait longer to be loaded and unloaded.

In this study, 86% per cent of the terminals demonstrate increasing returns to scale (IRS). The terminals are expected to expand their operations through internal growth and alliance building among shipping companies. The Container terminals experiencing declining returns to scale may be expanding their operations beyond their optimal capacity, increasing costs and decreasing efficiency. When constant returns to scale are experienced, it may be that the organization has reached its optimal capacity and can no longer achieve further efficiency gains without significant investment.

A container terminal is essential to any logistics and supply chain system. It is possible to reduce congestion, increase throughput, reduce operating costs, and improve overall productivity by improving technical efficiency. Utilizing the latest technology and infrastructure can improve a container terminal's efficiency. Increasing cargo handling speed and accuracy, reducing turnaround time, and enhancing overall productivity is possible by upgrading the terminal's equipment and infrastructure. Automated stacking cranes, guided vehicles, and gate systems can reduce human error, enhance operational efficiency, and boost throughput.

The Artificial Intelligence (AI), Machine Learning (ML), Radio Frequency Identification (RFID), Optical Character Recognition (OCR), Internet of Things (IoT), Cloud Computing(CC), Data Analytics (DA) and Digital Twins (DT) can help optimize operations, reduce delays, and improve customer service. Container terminals need to streamline their processes to increase efficiency. The process can be simplified by reducing paperwork, simplifying customs clearance procedures, and improving stakeholder communication. The technical efficiency of container terminals also depends on the workforce's skills and knowledge. Training and up-skilling programs can ensure employees are up-to-date with the latest technologies and best practices. Shipping terminals need seamless connectivity with rail and road networks. By improving connectivity, it is possible to reduce turnaround time, improve cargo movement efficiency, and lower operating costs. The operating costs of container terminals are heavily influenced by energy consumption. It is possible to reduce operating costs and improve overall efficiency by investing in energy-efficient technologies and practices, such as LED lighting, solar power, and energy-efficient equipment, electrically powered terminal

equipment. All stakeholders such as Government agencies, port operators, shipping lines, logistics companies and Transporters should all work together to improve the India's container terminals' technical efficiency. These suggestions will help container terminals improve efficiency, reduce costs, and enhance competitiveness.

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