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A novel Index-based quantification approach for port performance measurement: a case from Indian major ports

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ABSTRACT

This paper develops a unified port performance index (PPI) considering different cargo categories and the multi-dimensional nature of port performance indicators/dimensions. This study has used the quintile method to construct PPI. Further, the PPI obtained from the quintile method is compared with weighted unified index (PPI_{PCA}) using principal component analysis (PCA), extensively used for index development in the literature. A pilot index development is demonstrated using secondary panel data for 12 major Indian ports on five significant dimensions, namely, operations, physical infrastructure, technical infrastructure, finance, and socio-economic. Results show that the JNPT port outperforms all other ports under the container cargo category. Likewise, Kandla port in the liquid port category and Paradip port in the other (dry & break bulk) cargo category are on top. Also, qualitatively similar results and insights are obtained with the PPI_{PCA}. Subsequently, the panel data regression and efficiency analysis are performed to demonstrate the utility of the proposed index. The results affirm that the operations, physical infrastructure, and socio-economic dimensions have a positive and significant impact on port financial performance. The present study operationalises some key unexplored port performance indicators/dimensions that can enable effective decision-making.

KEYWORDS

Port performance index; performance indicators; port performance measurement; port competitiveness; port selection; benchmarking

1. Introduction

In maritime logistics, seaports (or ports) are the key nodes that act as a buffer and serve as the backbone for maritime supply chains (Rodrigue and Notteboom 2009). They significantly contribute to the global supply chain and connect logistics networks (Ha and Yang 2017). However, multiple users and competing interests make port operations a complex system, thus, making it difficult for port managers to make effective decisions (Ha, Yang, and Lam 2019). Performance measurement has a strategic value in identifying the potential barriers and ensuring the resilience of the system (Liu et al. 2019). Therefore, measuring and monitoring port performance is paramount to increasing productivity and diagnosing inefficiency causes (Munim and Schramm 2018). In the absence of an industry-standard performance measurement process, it becomes difficult to conduct comprehensive performance analysis and comparison globally (J. Chen et al. 2018; Lee and Yang 2018). Moreover, appropriate analytical tools are needed to improve port operations and provide

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a basis for potential port development planning (Chen et al. 2016). These analytical tools should capture different aspects of the maritime supply chain to have a more holistic view of port performance (Chen et al. 2020).

Port performance measurement (PPM) has recently received significant attention from academia and maritime industries (Dayananda Shetty and Dwarakish 2020 ; Molavi, Lim, and Race 2020; Nguyen et al. 2016). While these studies are insightful and show the importance of port performance measurement, we summarise some significant limitations hereafter. First, the existing literature primarily emphasises container cargo operations and largely ignores break bulk, dry bulk, and liquid bulk cargoes (Park, Lee, and Low 2020). These cargoes constitute a significant part of the port's financial transactions ('Review of Maritime Transport' 1974). Second, very few studies have simultaneously considered multi-stakeholder perspectives (such as port authorities and port users) while addressing port performance measurement (Vaggelas 2019; Ha, Yang, and Lam 2019). Third, the existing studies have mostly emphasised operational and financial aspects and ignored the socio-economic aspects to measure port performance (Chen et al. 2018). Fourth, managing port without compromising the performance is challenging as there exists a high level of interdependencies and interactions among performance indicators (Ha and Yang 2017). Thus, the decision to consider any specific indicator may positively or negatively impact another indicator, which eventually forces the port manager to determine the composition of port-level performance indicators optimally.

Moreover, individual performance indicators may not do justice to port performance assessment and may emphasise specific indicators at the expense of others (Jacobs 2013). As a result, we cannot just focus on individual port performance indicators in isolation. Therefore, future research needs to propose benchmarking indicators such as a composite index (Jung and Casello 2020) to enable port-related reforms. It is essential to highlight that the port performance index has the potential to break up the rigid borders between the different functional departments by building a standardised primary evaluation platform (Kavilal, Prasanna Venkatesan, and Harsh Kumar 2017). Despite the importance of developing a holistic index for practical port assessment (Kavilal, Prasanna Venkatesan, and Harsh Kumar 2017), past studies have given limited attention to an 'index approach' to quantify port performance. Finally, almost all the studies on port performance measurement are either conceptual or rely on survey/qualitative data, as secondary data availability is limited to very few higher authorities (Kutin, Nguyen, and Thomas 2017). It is important to note that qualitative data may affect the responders' attitudes and cognitive ability (Hammarberg, Kirkman, and De Lacey 2016).

In light of these limitations, the main contribution of this paper is to develop a unified port performance index (PPI) considering the multi-dimensional nature of port performance indicators. The proposed PPI deploys socio-economic and infrastructural indicators in addition to operational and financial dimensions. To the best of our knowledge, this is the first study that has developed PPI considering different cargo categories and multi-stakeholder's perspectives in PPM using secondary data. Also, this study introduces some unexplored port performance indicators and identifies critical dimensions using the PCA (principal component analysis) approach.

The remainder of the paper is structured as follows. The following section presents the literature review to select diverse dimensions and associated indicators. Section 3 explains the data and the index construction methodology considering Indian major ports. Later in section 4, we have presented and discussed the results. Also, we present the regression and efficiency analysis as an additional utility of port performance measurement. Section 5 presents the theoretical and managerial implications. Lastly, the paper concludes with recommendations for further research.

2. Literature review

Port performance measurements (PPM) are generally referred to as a measurement of operational efficiency (Diakomihalis, Kyriakou, and Sideris 2021), effectiveness (Brooks, Schellinck, and Pallis

2011), service quality (Ha, Yang, and Lam 2019), port selection (Tongzon 2009), productivity (Wiegmans, Witte, and Spit 2015), and port competitiveness (Lagoudis, Theotokas, and Broumas 2017; Aksoy and Durmusoglu 2020). PPM is a challenging exercise involving a sheer number of parameters, up-to-date and reliable factual data, acceptable definitions, and consistent interpretations of identical results (UNCTAD 2016). Thus, preparing a common framework for measuring port performance requires a pragmatic approach while selecting the port dimensions and the performance indicators. The UNCTAD (1985) published a monograph to encourage countries to develop a coherent framework for data collection in the same line of work. Ha, Yang, and Lam (2019); Lu, Shang, and Lin (2016) have evaluated the port performance considering different perspectives by collecting inputs from shippers, freight forwarders, port managers, terminal operators, logistics service providers, transport firms, and of course the port authorities and administration.

To this end, data-driven assessment needs emphasis to eliminate bias in opinions and comments (Hammarberg, Kirkman, and De Lacey 2016). Thus, the measurement framework should include secondary data from diverse dimensions such that the reliable data from the port can be utilised. L. Chen et al. (2016) and Ha et al. (2017) affirmed that it is not easy to decide on the set of indicators for a systematic comparison across the ports as they vary significantly with the type of cargo handled, size of traffic, demographic factors, and various operations regulation. There are no standard indicators and methodologies to measure the port performance, which is informative and consistent (Chen et al. 2016). However, various productivity indicators like cargo throughput (tonnage or volume of cargo handle) or total traffic (TEUs) are commonly used in the literature to project the port performance (Hossain et al. 2019). Other indicators like berth occupancy, crane efficiency, yard utilisation, turnaround time, operating income, and net profit are referred to in the existing literature (Ha and Yang 2017; Ha, Yang, and Lam 2019). Also, the port efficiency and effectiveness aspects of PPM have been widely researched for decades using productivity indicators (Lagoudis, Theotokas, and Broumas 2017). Definitions of the chosen dimensions with their associated indicators are provided below.

2.1. Operational indicators

This dimension relates to the core port functions like vessel operations, cargo operations, and other operations in the maritime supply chain. Different terminology like productivity, throughput, and capacity utilisation have been traditionally utilised to measure the port performance, efficiency, and effectiveness (Brooks and Pallis 2008; Rosa et al. 2013; UNCTAD 1985; Vaggelas 2019). Indicators that deal with the time and output/throughput aspects are generally made public through the port authorities. The combination of these indicators measures operational competitiveness (Ha et al. 2017). Different time-related taxonomies like the turnaround, dwell, pre-berthing, and idle time are relevant to measure port performance (Shetty and Dwarakish 2020; UNCTAD 2016). The term output refers to the total work performed at a port in a specific period (UNCTAD 1985). Total vessel handled or traffic handled is a commonly used output indicator in the existing literature (Kuo, Lu, and Le 2020). Output also considers productivity indicators like average output per ship berth day and average berth occupancy, reflecting how efficiently the resources are utilised.

2.2. Physical infrastructural indicators

Port infrastructure typically refers to the land and the permanent assets/equipment configured for necessary service at the port (UNCTAD 2016). Physical infrastructure is the fixed and immovable parts of a harbour, such as lands, roads, quay walls, and hinterlands, providing the base for port operations (UNCTAD 2016). Typical physical infrastructural indicators in the existing literature are berth length, terminal area, transit shed area, storage area, warehouse area, and open area (Munim and Schramm 2018; UNCTAD 1987). Unfortunately, these indicators and the infrastructure data at the port level are not utilised properly, leading to under usage and inefficiency (Kutin, Nguyen, and Thomas 2017).

2.3. Technical infrastructural indicators

Technical infrastructure refers to the movable and quayside superstructure. These enable necessary services and equipment for cargo handling operations. Systematic investment in equipment, their process, and periodic maintenance of facilities cover a significantly high cost. The UNCTAD (1987) reported that the capital costs for technical infrastructure involve almost 50% of the total investment. Technical infrastructural indicators commonly used in PPM are the availability and utilisation of port equipment like gantry cranes, quay cranes, mobile cranes, tractors, and other special-purpose equipment like dredging facilities (Chen et al. 2020; Suárez-Alemán et al. 2016). López-Bermúdez, Freire-Seoane, and Nieves-Martínez (2019) evaluated the efficiency of Argentina's port terminals by considering the infrastructural indicators like the number of gantry cranes, mobile cranes, and frequency of calls.

2.4. Financial indicators

Financial indicators refer to the indicators that showcase the firm's financial profitability and viability (e.g., profit extracted from the revenue generated through operations) (Brooks and Pallis 2008). These indicators form the basis of port efficiency measurement to analyse its performance with self and with competitor ports on a year-by-year basis. In the series of literature by Brooks and Pallis (2008,2011), indicators like capital expenditure as a percent of gross revenue, debt to equity ratio, profit before tax, return on capital employed, total revenue, and net operating profit are utilised to assess port governance models. This line of work is evident from the monograph of UNCTAD (1976), which gave an exclusive list of financial indicators. In the recent series of reports from UNCTAD (UNCTAD 2016), operating margin, revenues from vessel dues, cargo dues, rents, and other fees are also considered the financial indicators. Ha, Yang, and Lam (2019, 2017) have considered operating profit margin, net profit margin, debt to total asset, and debt to equity under the financial strength dimension. Su et al. (2003) used profitability, solvency, and return on investment as economic indicators for preparing the balanced scorecard.

2.5. Socio-economic indicators

Socio-economic indicators refer to the integration of social, environmental, and economic aspects. Ports form an essential part of overall socio-economic development (Asgari et al. 2015). The social element aims to improve the well-being of society, and the economic aspect seeks to optimise the operations, reduce costs, and create value-added services (Denktas-Sakar and Karatas-Cetin 2012). Despite the wide adoption of socio-economic indicators in other fields, its implementation in the maritime industry is relatively recent (Lam 2015). Also, the focus on fulfilling corporate social responsibility has sharpened in recent years. Ha et al. (2017) reported that the ports could contribute to a greater extent to developing skills and generating employment. Woo et al. (2011) and Ha, Yang, and Lam (2019) considered 'employment' as an indicator of sustainable growth. Thus, considering the factors that focus on achieving long-term socio-economic development brings a new direction to PPM.

Table 1 presents the abovementioned dimensions and the relevant quantitative indicators used in extant literature to measure different aspects of port performance. Some of the aspects mentioned in Table 1 are operational and financial performance, efficiency, effectiveness, and productivity. We identify that the literature has ignored the liquid bulk (O11) and other bulk cargo (O12). Also, indicators reflecting ports' distribution capacity like the channel depth and width (I1, I2), transit shed area (I5), and warehouse area (I6) are ignored and least utilised (Junior et al. 2003). The

Table 1. Literature related to port performance indicators.

References	Dimensions and Key Indicators*																																Objective
	Operations												Infrastructure										Finances						Socio-economic				
	O1	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**	**I10**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**S1**	**S2**	**S3**	**S4**	**(Measure of)**
Brooks (2006)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	✓	✓	✓	-	-	-	-	Financial performance
Chou (2007)	-	✓	-	-	✓	-	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	Port selection
Brooks and Pallis (2008)	✓	-	✓	✓	✓	-	-	✓	✓	-	-	-	-	-	✓	-	-	-	-	-	-	✓	✓	-	✓	-	✓	-	✓	✓	-	-	Port effectiveness
Tongzon (2009)	✓	-	-	✓	✓	-	-	-	-	✓	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Port selection
ESPO-PPRISM (2010)	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	Port indicators
Hung et al. (2010)	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	✓	✓	-	-	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	Port efficiency
Wu and Goh (2010)	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	✓	-	-	-	✓	-	-	✓	-	-	-	-	-	-	-	-	-	-	Port efficiency
Woo et al. (2011)	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Port productivity
Brooks et al. (2013)	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Port effectiveness
Wiegmans, Witte, and Spit (2015)	-	-	-	✓	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	Port productivity
Chen et al. (2016)	-	-	-	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Operational performance
Suárez-Alemán et al. (2016)	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	-	✓	-	✓	-	-	-	✓	-	-	-	Port efficiency
Ha and Yang (2017)	✓	-	-	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓	-	-	-	-	Port performance
Kutin, Nguyen, and Thomas (2017)	-	-	-	-	-	-	-	-	-	✓	-	-	✓	-	-	-	-	-	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	Port efficiency
PPORTOPIA (2017)	✓	-	-	✓	✓	✓	-	-	✓	-	-	-	✓	-	-	✓	✓	-	-	✓	-	-	-	-	-	-	-	-	-	✓	-	✓	Port indicators
Shetty et al. (2020)	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Port productivity
Ha, Yang, and Lam (2019)	✓	-	-	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓	-	-	-	-	Port performance

(*Continued*)

Table 1. (Continued).

References	Dimensions and Key Indicators*																																Objective
	Operations												Infrastructure										Finances						Socio-economic				
López-Bermúdez, Freire-Seoane, and Nieves-Martínez (2019)	-	-	-	-	✓	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-	-	-	Port efficiency
	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	✓	-	-	-	-	Port performance
Vaggelas (2019)	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	✓	-	✓	✓	✓	-	✓	-	-	-	-	-	-	-	-	-	-	Port effectiveness
Chen et al. (2020)	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	-	-	✓	-	-	Port efficiency
Kuo, Lu, and Le (2020)	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	✓	-	-	-	-	-	-	-	-	-	-	Port efficiency
Proposed framework	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**Unified PPI**

Operations: *O1- Avg. Turnaround Time, O2- Avg. Pre-berthing time/pre-berthing detention, O3- Vessel Idle time, O4-Average output or Throughput, O5-Vessel handles, O6-Average berth occupancy, O7-Container Traffic, O8-Import/Export cargo traffic, O9-Transhipment Cargo Traffic, O10-Container traffic, O11- Liquid bulk traffic, O12-Other cargo traffic;* ***Infrastructure:*** *I1-Entry channel Depth, I2-Entry channel width, I3-berth/quay length, I4: cargo category-wise berth, I5-Area of transit shed, I6- Area of warehouse, I7-Terminal area, I8-no. of wharf /Gantry cranes, I9-no. of mobile cranes, I10-number of forklifts and other equipment;* ***Finances:*** *F1-Total income, F2-Gross profit margin, F3-Capital employed, F4-Operating ratio, F5-Rate of return, F6-Operating surplus/ Net Profit;* ***Socio-economic:*** *S1-Staff salary, S2- staff strength, S3- staff medical expenditure, S4- CSR expenditure*

*indicates 'not included';

✓: indicates 'included'

proposed framework uses such indicators along with some frequently considered operational and infrastructural indicators like the average turnaround time (O1), cargo throughput (O4), no. of cranes/forklifts/other equipment (I8, I9, I10) (Suárez-Alemán et al. 2016; Chen et al. 2020; Kutin, Nguyen, and Thomas 2017). Nonetheless, the finance and socio-economic indicators are also prominent in the port performance measurement studies. Therefore, the proposed method uses all the indicators and introduces a unified PPI.

3. Data and methodology

3.1. Data description

The purpose of this research is to build a single unified index that takes into account five port dimensions. This work is based on data gathered from reputable and reliable secondary sources such as the Center for Monitoring Indian Economy (CMIE), Indiastat, yearly reports, and port websites (Siegel and Choudhury 2012). It analysed objective data on 12 major Indian ports from 2001 to 2018 (see Figure 1). The performance indicators in this research are organised in Figure 2 according to five critical dimensions: operations, physical infrastructure, technological infrastructure, financial, and socio-economic. The definitions of each indicator are presented in *Appendix A*. The dataset is freely accessible for use as a reference and may be retrieved through the URL appended at the end.

The dataset obtained has multiple missing observations during the period 2001–2018. Increasing the temporal span to the past would undoubtedly lower the data consistency. As a result, the six years (2012–2018) were considered to get a constant sample size. Additionally, the Ennore-Kamarajar port was excluded from our research owing to a lack of data, leaving the sample with

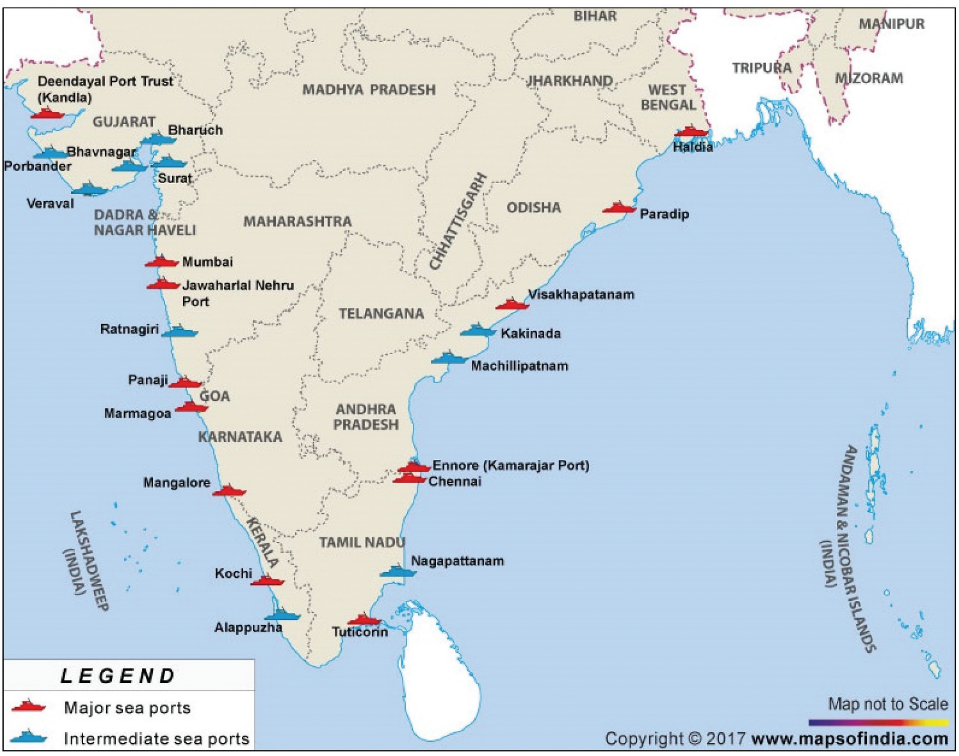

Figure 1. Major seaports in India (Source: http://www.mapsofindia.com).

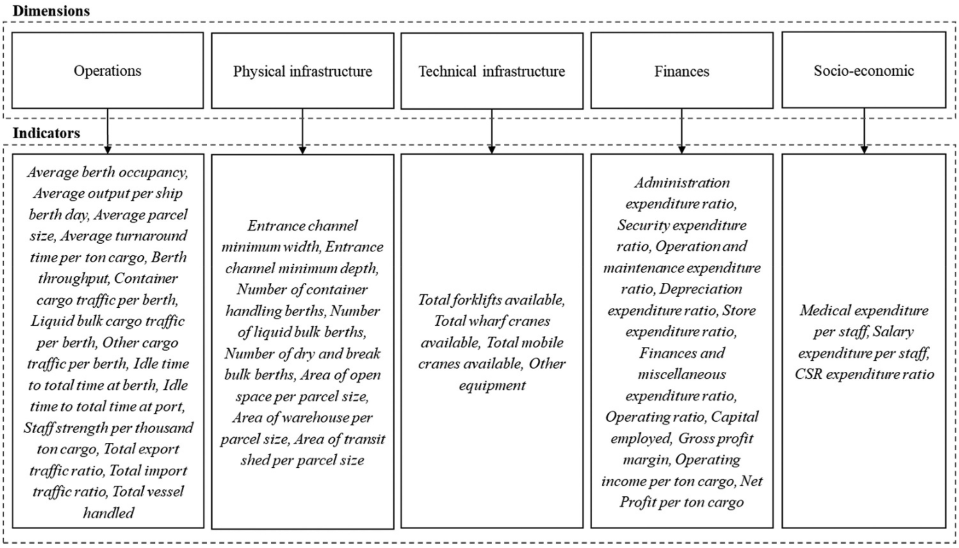

Figure 2. Dimensions and indicators considered for construction of PPI.

11 major Indian ports. Based on their infrastructure and operating requirements, these 11 ports were classified into three categories: container, liquid cargo, and other cargo types. Table 2 presents descriptive information for all indicators utilised to create the index for the container port category. The indicators representing time, area, and financial parameters are standardised using information like total traffic, the number of berths, and staff strength. The data is used without normalising to a standard scale since our suggested technique uses a distinct scale to approach the data.

3.2. Methodology

To develop the proposed unified PPI, two statistical approaches are used: Quintile analysis and principal component analysis (PCA). In the beginning, the PPI is generated using the quintile technique, and later, the PCA methodology is utilised to verify and confirm the results from the quintile method. Figure 3 presents a step-by-step procedure for selecting indicators, data collection, and data cleaning, followed by the construction of the PPI.

PCA is a well-known technique for creating an index (used in developing the Logistics Performance Index, LPI is coined by the World Bank) (Patil and Sharma 2020). Though it offers several advantages by removing correlated features and overfitting, it has some drawbacks (Karamizadeh et al. 2013). Implementing PCA requires standardised data; otherwise, PCA fails to find an optimal principal component (Jollife and Cadima 2016). Additionally, PCA may result in information loss if appropriate principal components are not selected to cover the maximum variance (Geiger and Kubin 2012). As a result, the quintile method was employed to circumvent the limitations of PCA. The quintile approach does not require standardised data; rather, it stratifies them into five values according to their distribution. Additionally, the quintile approach enables the incorporation of new dimensions to provide a unique perspective on performance measurement. The following section elaborates on the quintile and PCA approaches.

3.2.1. PPI using quintile approach

3.2.1.1. Quintile. A quintile is a value (or 'score') given to one of five equal groups obtained according to the data distribution of a particular indicator. Therefore, each quintile represents a different 20% range of the given dataset. The lowest quintile (i.e., value = 1) represents the lowest

Table 2. Data description for container ports.

Dimension- Operations					
Indicators (*Units*)	Mean	S.D.	Min	Median	Max
Average berth occupancy (*percent*)	60.05	10.09	38.8	60	83
Average output per ship berth day (*ton*)	13,647.81	6491.76	2988	13,298.5	26,308
Average parcel size (*ton*)	23,132.19	7431.41	7730	24,608.5	32,490
Average turnaround time per ton (*hours/ton*)	6.66	4.53	1.48	5.59	16.99
Berth throughput (x1000 *ton*)	2266.54	1491.71	358.91	2161.32	5374.17
Container cargo traffic per berth (x1000 *ton*)	4413.5	1672.25	1740	4344	7096
Liquid bulk cargo traffic per berth (x1000 *ton*)	3144	2169.71	202	3091	7555
Other cargo traffic per berth (x1000 *ton*)	1659.93	1499.18	150.54	999.33	4417.06
Idle time to total time at berth (*percent*)	23.01	6.4	10.8	23.65	35.4
Idle time to total time at port (*percent*)	16.76	6.86	5.1	17	33
Staff strength per thousand ton cargo (*numbers/ton*)	0.1	0.09	0.02	0.07	0.41
Total export traffic ratio (*percent*)	33.69	9.3	16.97	35.27	49.33
Total import traffic ratio (*percent*)	63.74	10.8	44.14	64.24	81.55
Total vessel handled (*numbers*)	1693	551	875	1600	2828
Dimension- Physical infrastructure					
Indicators	Mean	S.D.	Min	Median	Max
Entrance channel minimum width (*metres*)	187.33	115.86	45	168.5	450
Entrance channel minimum depth (*metres*)	13.01	3.48	8.9	10.85	18.6
Number of container handling berths (*numbers*)	4.17	2.95	1	3	9
Number of liquid bulk berths (*numbers*)	3.67	2.2	1	3	7
Number of other cargo berths (*numbers*)	13.64	6.54	1	14	24
Area of open space per parcel size (m^2/*ton*)	30.47	25.68	5.72	23.1	119.52
Area of warehouse per parcel size (m^2/*ton*)	14.27	39.83	0.16	1.25	171.61
Area of transit shed per parcel size (m^2/*ton*)	8.88	11.89	0.19	1.06	31.75
Dimension- Technical infrastructure					
Indicators	Mean	S.D.	Min	Median	Max
Total forklifts available (*numbers*)	10.19	9.05	1	10	30
Total wharf cranes available (*numbers*)	5.03	6.42	1	3	19
Total mobile cranes available (*numbers*)	3	2.55	1	2.5	10
Other equipment (*numbers*)	99.28	134.03	1	30	429
Dimension- Finance					
Indicators	Mean	S.D.	Min	Median	Max
Administration expenditure ratio (*percent*)	1.68	1.32	0.33	1.64	7.8
Security expenditure ratio (*percent*)	3.59	1.21	1.79	3.63	7.7
O&M expenditure ratio (*percent*)	12.11	5.32	3.32	11.05	23.12
Depreciation expenditure ratio (*percent*)	4.29	1.34	1.88	4.28	10.02
Store expenditure ratio (*percent*)	2.5	1.81	0.34	2.3	6.84
Finances and misc. expenditure ratio (*percent*)	38.33	16.05	0.97	42.05	74.05
Operating ratio (*percent*)	67.89	20.03	39.55	69.67	117.9
Capital employed (*INR in millions*)	21,229.91	25,427.14	−1300.2	13,028.25	107,885
Gross profit margin (*percent*)	32.11	20.03	−17.9	30.33	60.45
Operating income per ton cargo (*INR in millions/ton*)	336.9	382.36	117.47	168.01	1330.5
Net profit per ton cargo (*INR in millions/ton*)	14.44	92.22	−251.79	5.88	218.51
Dimension- Socio-economic					
Indicators	Mean	S.D.	Min	Median	Max
Medical expenditure per staff (*INR/employee*)	64,943.54	33,505.21	14,147.06	62,922.36	141,755
Salary expenditure per staff (*INR/employee*)	914,502.6	294,673.1	459,725.3	829,883.2	1,650,734
CSR expenditure ratio (*percent*)	0.57	2.89	−7.49	0.3	10.7

fifths of the dataset (1% to 20%), and the highest quintile (i.e., value = 5) represents the top fifths (81% to 100%). For instance, if the total vessel handled by a list of ports in a particular year is closely observed, the ports in the lower quintile (value = 1) take the least amount of ship vessels annually. The quintile value and its representation for the entire data range are shown in Figure 4.

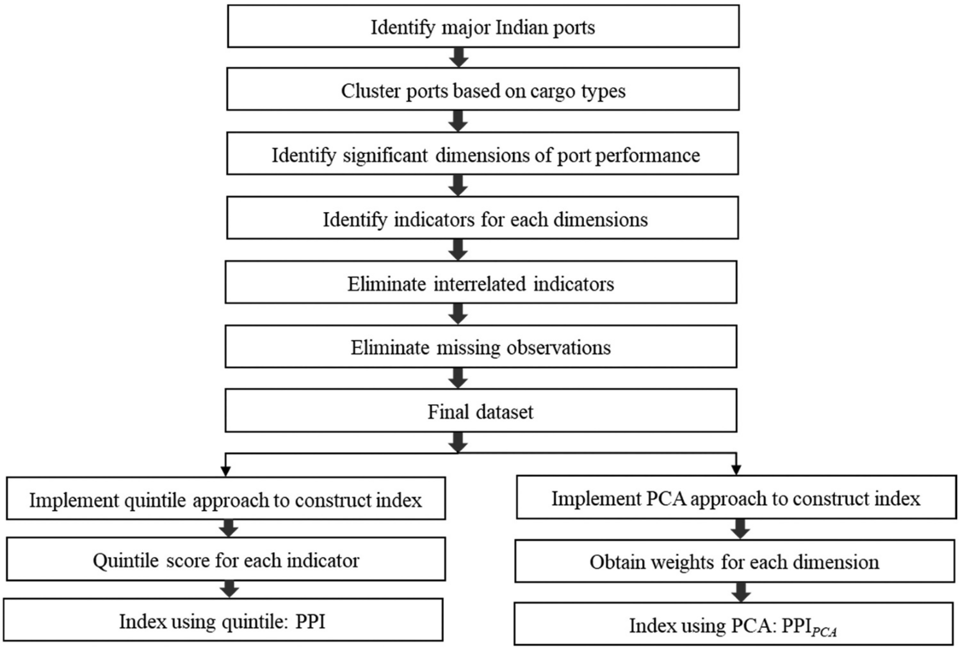

Figure 3. Steps for PPI construction.

The schematic representation to deploy the quintile approach is presented in Figure 5. Table 3 shows the construction of a unified PPI using the quintiles with a numerical example. As explained, the quintile scores are obtained for each indicator. These scores are then reversed for indicators that negatively correlate with productivity and efficiency (for example, time parameters; lesser the turnaround time, better the performance) to maintain their significance. Further, the quintile scores for indicators under each dimension are added to obtain the dimensional index (operation index- *OI*, physical infrastructure index- *PI*, technical infrastructure index- *TI*, socio-economic index- *SI*, and financial index- *FI*). Finally, the PPI and rank for each port are obtained by aggregating these dimensional indices, as shown in Table 3.

Additionally, this study uses principal components analysis (PCA) to validate the findings of the quintile approach. The subsequent section explains the PCA approach in detail.

3.2.2. PPI using principal component analysis (PCA) approach

3.2.2.1. PCA. To construct the weighted index, each dimension is weighed appropriately, for which PCA was used. PCA simplifies the complexity of high-dimensional data while retaining the trends and patterns (Lever, Krzywinski, and Altman 2017). It reduces data by geometrically projecting (called orthogonal transformation) onto lower dimensions called principal components (PCs). It provides the best summary of the data using a limited number of PCs such that they capture the maximum possible variance. The variance information is used to identify weights for each dimensional index and construct a unified weighted index called PPI$_{PCA}$.

3.2.2.2. Calculation of weights and port ranking. The dimensional indices obtained from the quintile approach are considered as input to PCA. Further, the PCs with cumulative variance greater than 80% or Kaiser's rule (retaining only those PCs whose eigenvalues are greater than one) are selected. The selected PCs covering maximum variance are then used for calculating weights and constructing the index. A snippet of the PCA output is shown in Table 4 and Table 5.

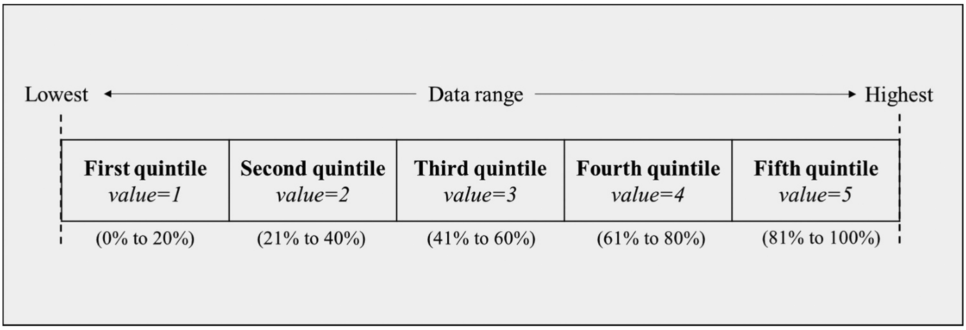

Figure 4. Quintile value.

The principal components that meets the selection criteria are used to calculate the weights. Now, the loadings for corresponding components are varimax rotated to enhance the results' interpretability. It produces a final set of component loadings (for instance, three components for each category of ports). These are then converted into a single weight through a proportion of overall variance explained by each component and the share of variance explained by each dimensional index in respective components. The procedure for estimating weights is elaborated with a numerical example in Table 6. This estimated weight is then used to calculate the overall score, which is given by $PPI_{PCA} = \sum W_j * (OI + PI + TI + FI + SI)$, where W_j is the weights for each dimension. Finally, the ranking is obtained based on the PPI_{PCA} score.

3.2.3. Validation of PPI

The study also examines the relationship between port dimensions (*OI*, PI, *TI*, and *SI*) and financial performance (*FP*) using panel data regression. Eq. (1) present the regression model used to validate the dimensional constituent of PPI.

$$(FP)_{it} = \beta_0 + \beta_1(OI) + \beta_2(PI) + \beta_3(TI) + \beta_4(SI) + year\ dummy\ +\ cargo\ dummy\ +\ \varepsilon_{it} \quad (1)$$

where,

FP- port financial performance is proxied by a composite form of profit after tax, operating profit, and return on capital employed, β = coefficient, ε_{it} *= error*

Year and cargo dummy are used in the regression model to cater for the multiple years and multiple cargo categories. Furthermore, the test statistics consider robust standard errors that consider heteroskedasticity.

4. Results and discussions

This section presents the results from the quintile approach (PPI) and the PCA approach (PPI_{PCA}) based on the secondary data for selected port dimensions and indicators. This section presents the progression of PPI over the period 2012–2018, its analysis, and the port's ranking. After that, the PPI is compared with PPI_{PCA} results to validate the findings from the proposed approach. In the latter part of this section, the efficiency (using DEA) and regression (using OLS) analyses are presented to demonstrate how the proposed index is ahead of existing indicators for performing additional analysis.

4.1. Index using quintile approach: PPI

4.1.1. Progression of PPI

The year-wise PPI for 2012–2018 is presented for each container port, liquid bulk po, and dry bulk ports (see Figure 6a–c). It is seen that JNPT has been consistently doing well over the

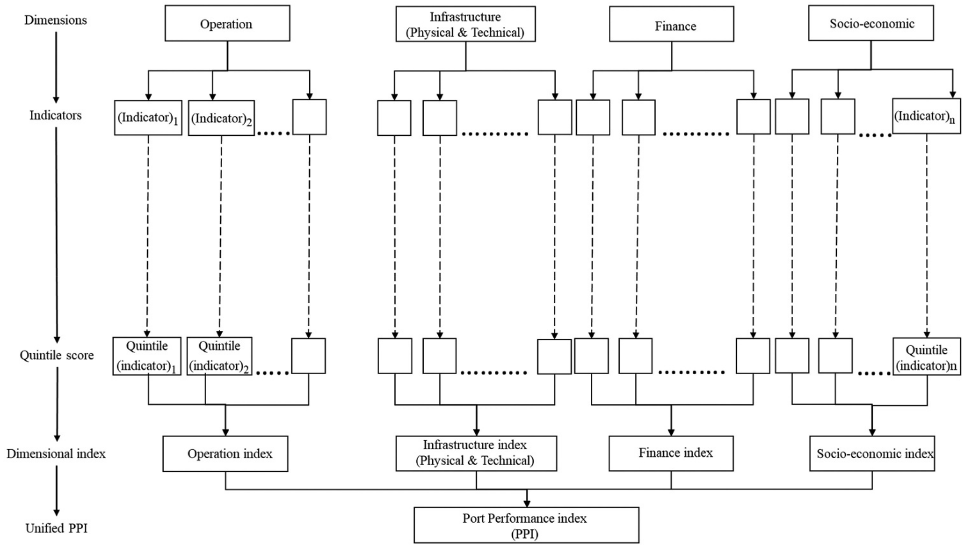

Figure 5. Schematic of PPI construction.

years, with a high average PPI score of 145 for 2012–2018. JNPT (2015–2016) has the best performance in the container ports category. Likewise, the Kandla port (during the year 2016–2018) in the liquid ports category and the Paradip port (during the year 2013–2014) in the other (dry & break bulk) cargo category have the best PPI score.

The average value of each dimension index is shown in Figure 7, along with the average PPI score for each port category. Interestingly, the average PPI score for (under container port category) Chennai and VOC-Tuticorin port is comparable. Although their average score varies marginally, the physical and technical infrastructural index is higher for VOC-Tuticorin port than for Chennai. It implies that VOC-Tuticorin performs better with less infrastructural capabilities and is more efficient than Chennai port. Consequently, the efficiency perspective of PPM could be addressed using such port-level analysis. By closely observing the index variability over the years, the port management can make effective decisions on port reforms. Investment decisions on enhancing the technical and physical infrastructural capabilities could be addressed simultaneously while observing the short-comings of overall port performance.

4.1.2. Ranking of ports with PPI score

Table 7 presents the top three and bottom three major ports of India as per the PPI scores for each of the three cargo categories *(Refer to Appendix B for a complete list of ports PPI scores and ranking)*. The port's ranking as per PPI score reveals the inter-port and intra-port competitiveness. For instance, the score for JNPT in the container port category is higher during 2015–2016 than in 2016–2017. This is due to its higher score for financial and socio-economic dimensions. Further cascading at the indicator level reveals that JNPT made a lesser expenditure in 2015 (expenditure on administration, security, stores) and had less operating ratio, which ultimately led to more profit and higher CSR expenditure (socio-economic advantage). Consequently, the PPI and port ranking investigates the intra-port performance over the years. This could form the basis of port competitiveness and bench-marking perspective of PPM.

Table 3. Numerical example for using quintile approach.

PPI for Chennai Port (2012) taken under container port category

Operation indicatorsthead	Data	Quintile value for operation indicators	Physical infrastructure indicators	Data	Quintile value for physical infra. indicators
Average berth occupancy	57.40	4	Entrance channel minimum width	244	4
Average output per ship berth day	12,485	3	Entrance channel minimum depth	18.6	5
Average parcel size	27,699	3	Number of container handling berths	7	4
Average turnaround time per ton cargo	5.21	3	Area of open space per parcel size	18.05	1
Berth throughput	2225.20	5	Area of warehouse per parcel size	0.88	1
Container cargo traffic per berth	4244	5	Area of transit shed per parcel size	1.02	2
Liquid bulk cargo traffic per berth	7343.50	4			
Other cargo traffic per berth	1016.80	1	**(B)** Physical infrastructure index *PI*		**17**
Idle time to total time at berth	25.20	2	**Technical infrastructure indicators**	**Data**	**Quintile value for technical infra. indicators**
Idle time to total time at port	17.40	5	Total forklifts available	10	2
Staff strength per thousand ton cargo	0.123	2	Total wharf cranes available	6	4
Total export traffic ratio	35.63	3	Total mobile cranes available	3	3
Total import traffic ratio	64.37	3	Other equipment	109	4
Total vessel handled	1880	2			
(A) Operational index *OI*		**45**	**(C)** Technical infrastructure index *TI*		**13**
Financial indicators	**Data**	**Quintile value for financial indicators**	**Socio-economic indicators**	**Data**	**Quintile value for socio-economic indicators**
Administration expenditure ratio	0.47	5	Medical expenditure per staff	42,160	1
Security expenditure ratio	4.07	3	Salary expenditure per staff	571,027	2
Operation and maintenance expenditure ratio	5.24	5	CSR expenditure ratio	4.11	4
Depreciation expenditure ratio	4.91	4			
Store expenditure ratio	1.42	4			
Finances and miscellaneous expenditure ratio	44.17	3			
Operating ratio	93.01	3			
Capital employed	20,067.3	4			
Gross profit margin	6.99	2			
Operating income per ton cargo	118.13	1			
Net Profit per ton cargo	3.42	2			
(D) Financial index *FI*		**36**	**(E)** Socio-economic index *SI*		**7**

PPI = Operation index + Physical infra. index + Technical infra. + Financial index + Socio-economic index
= (A) + (B) + (C) + (D) + (E)
= 45 +17 +13 +36 +7
= 118
Conclusion: PPI for Chennai Port (2012) under container port category is 118.

Table 4. PCA output for container port's analysis.

Principal components/correlation			Number of obs. =	36
			Number of comp. =	5
			Trace =	5
Rotation: (unrotated = principal)			Rho =	1
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	2.361	0.995	0.472	0.472
Comp 2	1.366	0.402	0.273	0.746
Comp 3	0.965	0.799	0.193	0.939
Comp 4	0.165	0.023	0.033	0.972
Comp 5	0.142	-	0.029	1.000

Table 5. Principal components.

Principal components (Eigenvectors)						
Dimension	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Unexplained
OI	0.461	−0.017	−0.684	0.038	0.563	0
PI	0.402	0.617	−0.193	−0.389	−0.520	0
TI	−0.182	0.777	0.231	0.358	0.428	0
FI	0.598	−0.103	0.219	0.713	−0.275	0
SI	0.485	−0.078	0.627	−0.459	0.393	0

Table 6. Numerical example for weight calculation.

(Weighted mean)$_j$ = $\frac{\sum (Proportion)_i.(Component)_{ij}}{\sum (Proportion)_i}$, where *i* is PCs (*here i = 1,2,3)* and *j* = {*OI*, PI, *TI, FI, SI*}; *ij* denotes value in the matrix in Table 5.

example: $\frac{(0.472*0.461)+(0.273*-0.017)+(0.193*-0.684)}{(0.472+0.273+0.193)} = 0.087$

(Weighted variance)$_j$ = $\frac{\sum (Proportion)_i.\left[\left((Component)_{ij}-(weighted\ mean_j)\right)\right]^2}{\sum (Proportion)_i}$

example: $\frac{\left[0.472*(0.461-0.087)^2\right]+\left[0.273*(-0.017-0.087)^2\right]+\left[0.193*(-0.684-0.087)^2\right]}{(0.472+0.273+0.193)} = 0.196$

(Weights)$_j$ = $\frac{(weighted\ variance)_j}{\sum (weighted\ variance)}$

example: $\frac{0.196}{0.620} = 0.316$

Dimension	Comp 1	Comp 2	Comp 3	Weighted mean	Weighted variance	Weights
OI	0.461	−0.017	−0.684	**0.087**	**0.196**	**0.316**
PI	0.402	0.617	−0.193	0.342	0.083	0.133
TI	−0.182	0.777	0.231	0.182	0.170	0.274
FI	0.598	−0.103	0.219	0.316	0.093	0.150
SI	0.485	−0.078	0.627	0.350	0.078	0.126
	Total =				0.620	1.0

4.2. Index using PCA: PPI$_{PCA}$

4.2.1. Ranking of ports with PPI$_{PCA}$ score

Three of five principal components met the criteria for selection, covering 94% of the variance. It means that these three components are sufficient to construct an index. Table 8 shows the weights calculated for each dimensional index using PCA. The weights indicate the priority of choosing a particular dimension for PPM and prioritising the investment decisions. For instance, the PPI$_{PCA}$ for container ports is majorly governed by operational indicators (0.32), followed by technical infrastructure (0.27) and financial infrastructure (0.15), which is in line with the findings of Ha et al. (2017). It suggests that container ports are susceptible to services (like less idle time, less TRT, good berth throughput) and dedicated facilities (like adequate storage space, availability, and equipment utilisation). Similarly, the infrastructural parameters (0.31 for physical and 0.26 for technical infrastructure) in liquid bulk ports are essential to overall performance, validating the need for

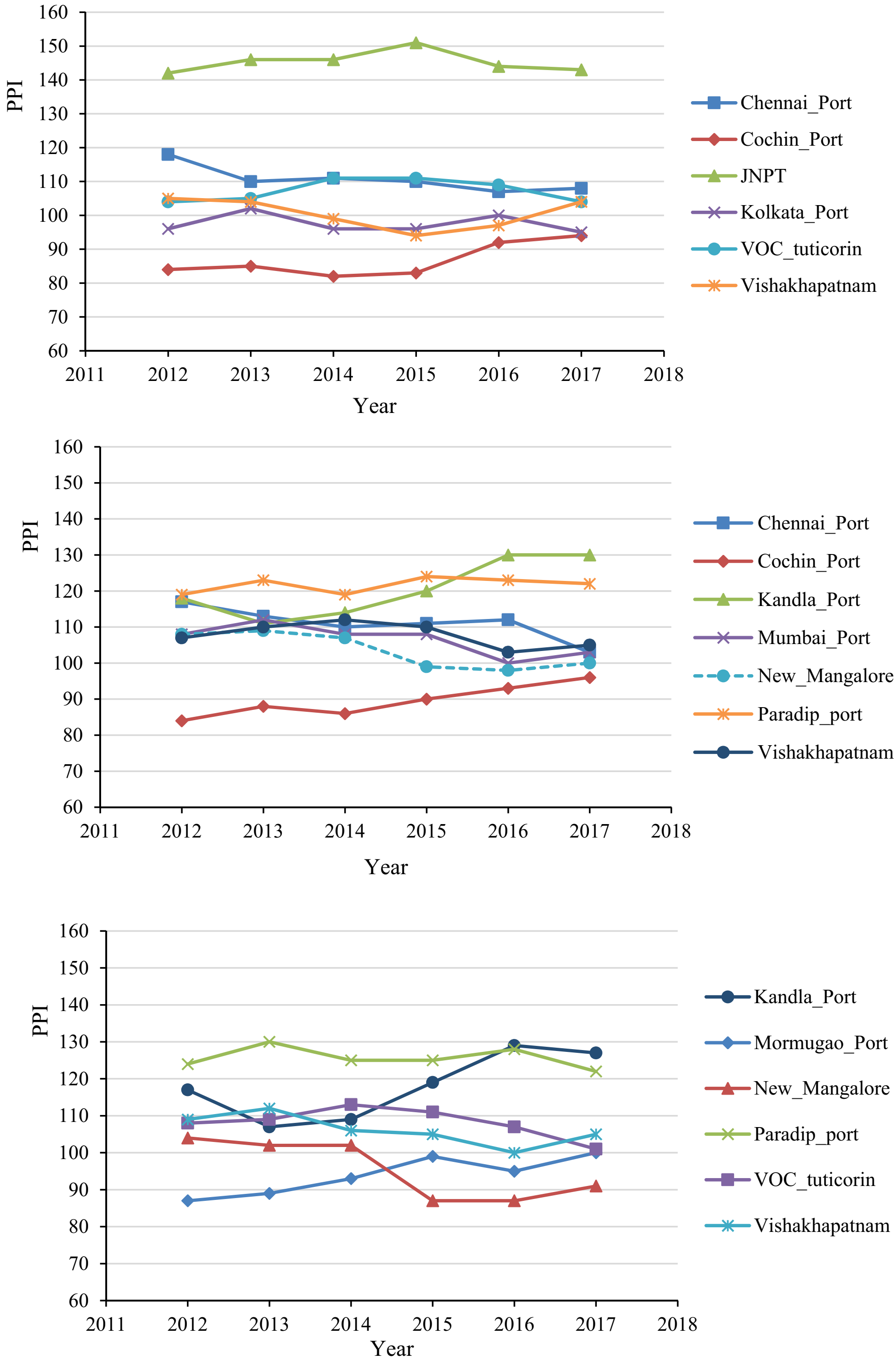

Figure 6. Progression of PPI for a.) Container ports, b.) Liquid bulk ports, and c.) Other ports (dry and break bulk).

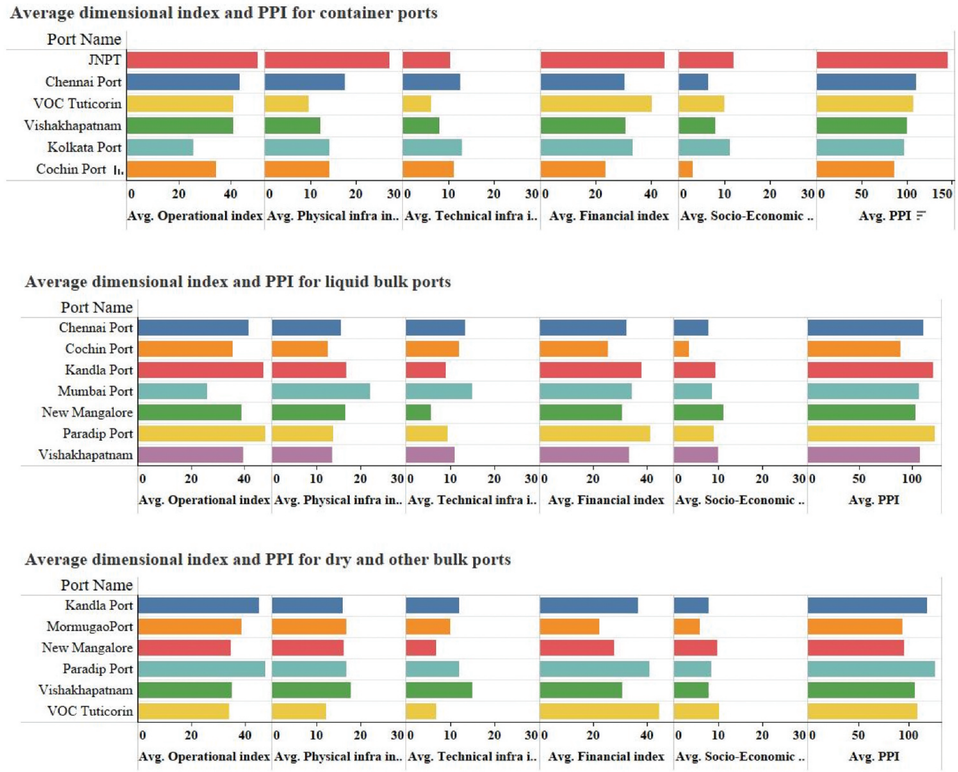

Figure 7. Cargo category wise port dimensional index and PPI.

Table 7. Top-3 and bottom-3 ports (category-wise) as per PPI.

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI	Rank	Port name	Year	PPI	Rank	Port name	Year	PPI	Rank
Top three ports											
JNPT	2015	151	1	Kandla	2016	130	1	Paradip	2013	130	1
JNPT	2013	146	2	Kandla	2017	130	2	Kandla	2016	129	2
JNPT	2014	146	3	Paradip	2015	124	3	Paradip	2016	128	3
Bottom three ports											
Cochin	2012	84	34	Cochin	2013	88	40	Mormugao	2012	87	34
Cochin	2015	83	35	Cochin	2014	86	41	New Mangalore	2015	87	35
Cochin	2014	82	36	Cochin	2012	84	42	New Mangalore	2016	87	36

Table 8. Weights calculated for port dimensions (category-wise).

	Weights for computation of PPI_{PCA}		
Dimensional Index	Container ports	Liquid bulk ports	Other cargo ports
Operations (*OI*)	0.316	0.186	0.055
Physical infrastructure (*PI*)	0.133	0.308	0.216
Technical infrastructure (*TI*)	0.274	0.26	0.057
Financial (*FI*)	0.150	0.026	0.296
Socio-economic (*SI*)	0.126	0.22	0.376

dedicated pipelines and handling facilities. Further, socio-economic parameters (0.38) and physical infrastructure (0.22) are critical to overall port performance for other cargo ports. It requires a high workforce and ample space for storage and transit.

Table 9 presents the top three and bottom three ports as per the PPI_{PCA} score for each cargo category *(Refer to Appendix C for the complete ports' PPI_{PCA} score and ranking)*. Such an index using the PCA approach could be obtained for any set of available data as it makes it easy to reduce the large attributes into a few principal components and eliminates the chances of losing essential information.

4.2.2. Comparison of PPI and PPI_{PCA} score

Figure 8a–c show the comparative chart for PPI and PPI_{PCA}. Here, multiplying the PPI_{PCA} score with a constant value derived by averaging the PPI and PPI_{PCA} score ratio manages the difference in the scale of the two scores. The constant value obtained for container ports is **4.6, 6.1** for liquid bulk ports, and **5.6** for dry & break bulk ports.

Table 9. Top-3 and bottom-3 ports (category-wise) as per PPI_{PCA}.

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank
Top three ports											
JNPT	2015	31.89	1	Kandla	2017	20.50	1	VOC Tuticorin	2014	23.98	1
JNPT	2014	31.36	2	Kandla	2016	19.80	2	Paradip	2016	23.13	2
JNPT	2013	30.89	3	Kandla	2015	19.52	3	Kandla	2016	22.70	3
Bottom three ports											
Cochin	2013	19.29	34	Cochin	2013	14.86	40	Mormugao	2013	15.03	34
Cochin	2015	19.16	35	Cochin	2012	14.83	41	Mormugao	2016	14.64	35
Cochin	2014	19.01	36	Cochin	2014	14.73	42	Mormugao	2012	14.20	36

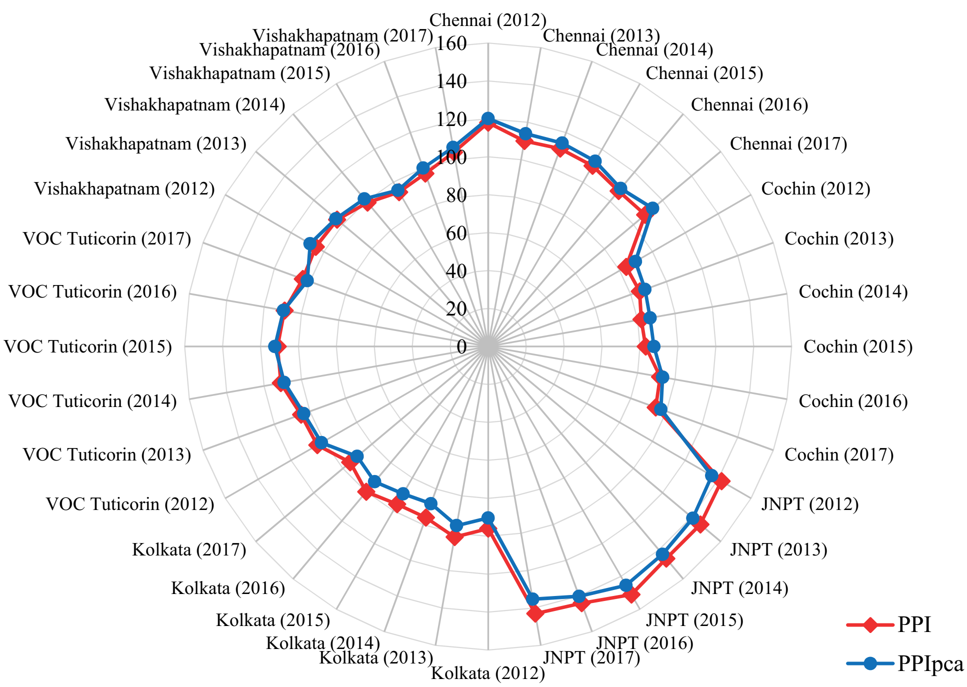

Figure 8. (a) Radar chart for container port's PPI and PPI_{PCA} score. (b) Radar chart for liquid bulk port's PPI and PPI_{PCA} score. (c). Radar chart for other cargo port's PPI and PPI_{PCA}.

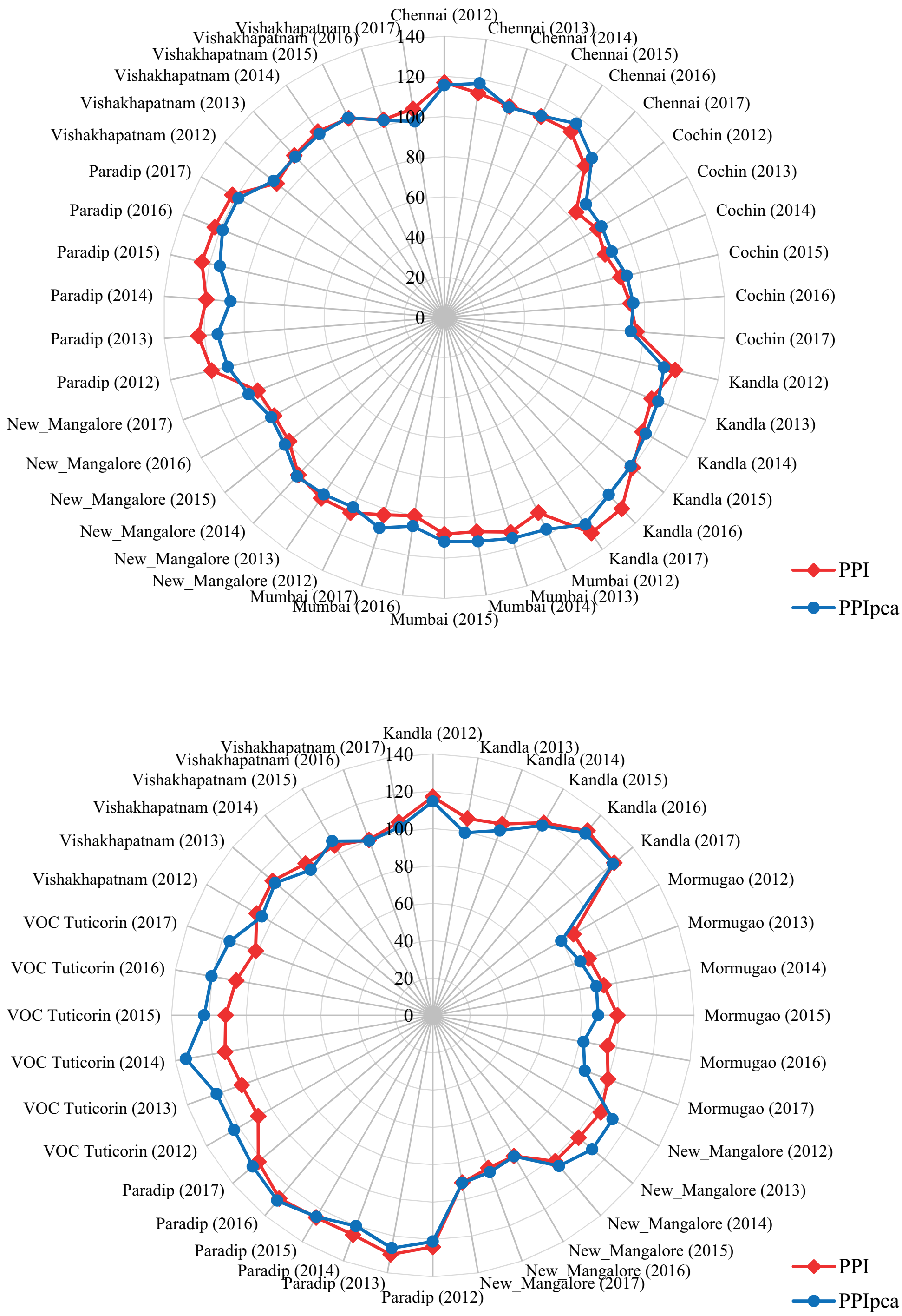

Figure 8. (Continued).

It is evident from the above comparison that the two scores consistently follow a similar trend. However, due to the distributed weights of the dimensions, the PPI_{PCA} score's transition over the years does not follow PPI for some ports. For example, even with the same operational and infrastructural setup, Kandla port (under liquid port category) has opposing trends from 2012 to 2013. This is due to the high socio-economic index score (socio-economic dimension has more weightage than financial dimension) due to their higher funding for CSR and medical benefits in 2013–2014.

4.3. Validation of PPI

The dimensional index obtained using the quintile method is utilised further to examine the impact of selected dimensions on port performance. In the latter part, it is being used as input and output parameters for efficiency analysis.

4.3.1. Regression analysis

Based on the standard Hausman test (see Table 10), the choice between the fixed effects and random effects estimators are made. Accordingly, the fixed effect panel data regression methodology is applied to our model.

Table 10. Output: Hausman test.

Coefficient				
	(b) fe	(B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
Operational index (*OI*)	−0.1018025	0.1816215	−0.283424	0.0367008
Physical infrastructure index (*PI*)	−0.319931	0.0306326	−0.3505635	0.0392713
Technical infrastructure index (*TI*)	−1.655241	−0.0466164	−1.608625	0.6610363
Socio-economic index (*SI*)	−0.321874	0.4915588	−0.8134328	0

Null hypothesis (Ho): The preferred model is random effects
Alternate hypothesis (Ha): The preferred model is fixed effects
b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg
Test: Ho: difference in coefficients not systematic
chi2(7) = (b-B)'.[(V_b-V_B)$^{-1}$].(b-B)
= 74.56
Prob>chi2 = 0.000
The value of p is significant. Therefore, we reject the null hypothesis. It implies that the fixed effect estimator is more suitable for our model.

Table 11. Relationship between port competency (in terms of operations, physical infrastructure, technical infrastructure, and socio-economic) and port financial performance.

Variables	Dependent variable: Port financial performance (FP) Model (1)
OI	0.2483***
	(0.068)
PI	0.2228**
	(0.088)
TI	−0.5614
	(0.341)
SI	1.4597***
	(0.136)
Constant	−6.4157***
	(2.389)
Year dummy	Yes
Cargo dummy	Yes
Observations	59
R-squared	0.681
Adj. R-squared	0.623

*** p <0.01, ** p <0.05, * p <0.10 (Robust standard errors in parentheses)

Table 11 presents the result obtained from the above equation (refer Eq. 1). It is observed that there is a positive (coefficient = 0.2483) and significant (at one percentile level) relationship between operational competence (measured by *OI*) and port financial performance (*FP*). Similarly, the results show that physical infrastructure competency (measured by *PI*) and socio-economic competency (measured by *SI*) has a positive and significant impact on port financial performance. The association between technical infrastructure competency and port financial performance is negative (coefficient = −0.5614). However, the relationship is insignificant. Overall, the results report that port competency in operations, physical infrastructure, technical infrastructure, and socio-economic is essential to enhance port financial performance. These results suggest that port operations, port infrastructure, and port-level corporate social responsibility (CSR) activities are the main determinants of port performance.

4.3.2. Efficiency analysis

4.3.2.1. Port's efficiency using Data Envelopment Analysis (DEA). The non-parametric approach with DEA is a proven methodology for conducting efficiency studies (López-Bermúdez, Freire-Seoane, and Nieves-Martínez 2019). DEA has an essential role in determining technical efficiency due to its flexibility to contain multiple inputs and outputs (Aparicio, Monge, and Ramón 2021). Unlike other methodologies (say, stochastic frontier analysis), DEA does not necessarily require a specific production function (López-Bermúdez, Freire-Seoane, and Nieves-Martínez 2019). They provide valuable information on whether a port or terminal is employing its inputs appropriately

Table 12. DEA results for container ports.

DMUs Port name (year)	Pure Technical Efficiency (PTE)	Overall Technical Efficiency (OTE)	Scale Efficiency (SE)
Chennai (2012)	87.2	85.6	98.2
Chennai (2013)	77.2	69.8	90.4
Chennai (2014)	81.0	77.5	95.6
Chennai (2015)	85.3	85.1	99.8
Chennai (2016)	81.7	74.3	90.9
Chennai (2017)	76.6	61.8	80.7
Cochin (2012)	**100.0**	81.1	81.1
Cochin (2013)	**100.0**	83.6	83.6
Cochin (2014)	**100.0**	74.5	74.5
Cochin (2015)	**100.0**	78.3	78.3
Cochin (2016)	**100.0**	**100.0**	**100.0**
Cochin (2017)	**100.0**	**100.0**	**100.0**
JNPT (2012)	**100.0**	90.3	90.3
JNPT (2013)	95.5	84.7	88.7
JNPT (2014)	81.7	79.0	96.6
JNPT (2015)	**100.0**	82.3	82.3
JNPT (2016)	95.0	86.7	91.2
JNPT (2017)	89.1	83.7	93.9
Kolkata (2012)	**100.0**	97.4	97.4
Kolkata (2013)	**100.0**	**100.0**	**100.0**
Kolkata (2014)	**100.0**	**100.0**	**100.0**
Kolkata (2015)	97.6	90.5	92.7
Kolkata (2016)	**100.0**	**100.0**	**100.0**
Kolkata (2017)	**100.0**	86.4	86.4
VOC Tuticorin (2012)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2013)	**100.0**	89.3	89.3
VOC Tuticorin (2014)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2015)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2016)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2017)	**100.0**	**100.0**	**100.0**
Vishakhapatnam (2012)	85.3	62.4	73.2
Vishakhapatnam (2013)	90.1	77.8	86.4
Vishakhapatnam (2014)	97.6	78.2	80.1
Vishakhapatnam (2015)	97.5	75.8	77.7
Vishakhapatnam (2016)	93.2	66.0	70.8
Vishakhapatnam (2017)	**100.0**	**100.0**	**100.0**

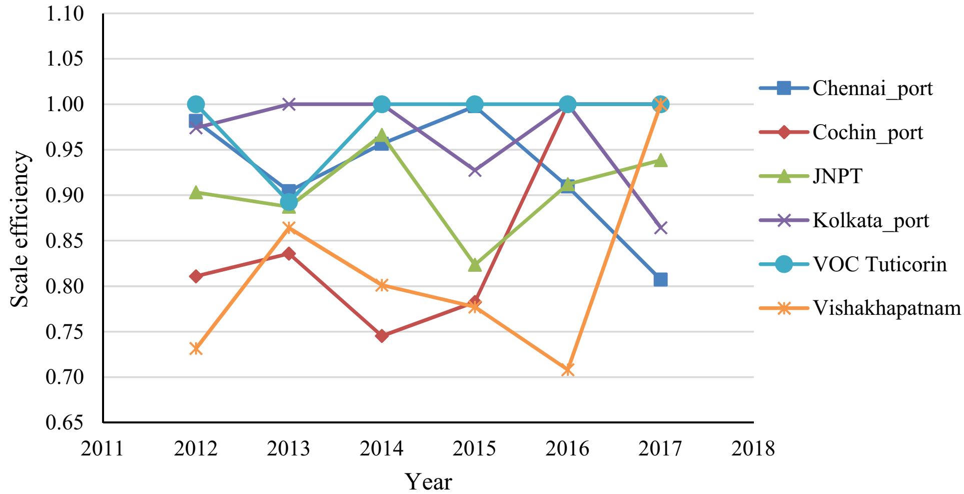

Figure 9. Scale efficiencies of container ports between year 2012–2017.

and making proper use of investments (Suárez-Alemán et al. 2016). DEA assesses the port efficiency and obtains the most efficient ones among other competitors, which serves as the benchmark port. Here, both the constant returns to scale (DEA-CCR[1] model) and variable returns to scale (DEA-BCC[2] model) are used to recognise the most efficient port. The port's efficiency is evaluated considering the dimensional index score (*Operational index, Physical infrastructure index, Technical infrastructure index, and Socio-economic index)* as input and the financial dimension (viz. *Financial index*) as output. Further, the scale efficiency[3] (SE) is calculated using the overall technical efficiency (OTE) from DEA-CCR and the pure technical efficiency (PTE) from DEA-BCC models. Table 12 reports the DEA results for container ports during the period 2012–2018.

Overall, the 36 ports {container ports (year)} are considered here as the decision making units (DMUs) for efficiency analysis. Of the 36 DMUs, 11 are technically efficient since they all have the OTE score of 100. It is evident that VOC-Tuticorin (2012, 2014, 2015, 2016, 2017), Kolkata (2014, 2016), and Cochin ports (2016, 2017) define the efficient frontier and, thus, can be treated as the benchmark for other inefficient ports. Also, the frequency of being efficient tells us that the VOC-Tuticorin port follows the best practices. Figure 9 shows the scale efficiency for the VOC-Tuticorin container port is 100% and consistent over the year. It reflects that the port administrations manage their operations, infrastructures, and finances better than other ports. The DEA results for liquid bulk and other cargo ports are available in Appendix D.

The dimensional and the unified indexes contain the essential information by capturing the variability in the data. Thus, it can be directly deployed in making other performance assessments, such as for measuring productivity, competitiveness, and port choice.

5. Research implications

This study has developed a unified index using secondary data considering different cargo categories and the multi-dimensional nature of port performance indicators/dimensions and subsequently validates the utility of the proposed PPI. The results of our study have several important theoretical and managerial implications.

5.1. Theoretical implications

This study focuses on the port's performance assessment by segregating them as per the category of cargo handled. It considers the quantitative indicators under different dimensions that monitor performance and value over time. Besides frequently cited indicators like cargo traffic, turnaround time, operating profit, and port capacity parameters, our study uses new ones to cater to the socio-economic aspects. The results indicate that the ports that topped the list are consistently better than other ports in most aspects. Average turnaround time per ton cargo, berth throughput, import/export traffic, staff strength per thousands of tons, open/warehouse/transit shed area per parcel size, medical/salary expenditure per staff, and CSR contribution as a percentage of total profit are some of the new indicators used in this study. The proposed methodology allows the flexibility to append new dimensions or indicators in any scale/unit.

Further, this study utilises PCA to obtain weights for different dimensions and reveals the significant dimensions for overall port performance. It uses finance-related quantitative data that are arcane and provides a quick summary. Nonetheless, the efficiency analysis objectifies that a port with high financial returns may not be efficient.

5.2. Managerial implications

The qualitative port performance indicators are ambiguous and rarely used to measure port performance (Ha et al. 2017). The proposed methodology uses the standard port indicators mentioned in UNCTAD (2016), readily available on most port websites. Therefore, internal (port authorities) and external stakeholders (shippers and freight forwarders) could use the proposed PPI to benchmark the ports' performance in a region. The availability of a unified PPI enables the stakeholders' to make decisions regarding port investments, improvising port competitiveness, efficiencies, and reliability of the complete port ecosystem. The PPI would aid the port authorities to prioritise the investments in improving infrastructural capabilities or making the operations effective and efficient. The emerging and developing ports could improve port attractiveness by comparing and mending the shortcomings. Specifically, it identifies the technical progress, over-usage, and under-usage of resources through performing the efficiency analysis. In addition, the proposed framework can be worked out to assess operational and financial stability by varying the inputs to the desired level.

6. Conclusion, limitations, and future scope

This study proposes a PPM framework based on elementary statistical analysis and presents a unified performance index, the PPI. A pilot measurement is shown based on the secondary data obtained for Indian major ports. It incorporates multi-dimensional aspects like operations, physical infrastructure, technical infrastructure, socio-economic, and finances to make the findings useful for various stakeholders. Previous studies on port performance generally considered qualitative surveys and limited quantitative indicators. Moreover, they typically considered the container ports and largely ignored the ports carrying liquid bulk, dry, and break bulk cargo. This paper develops a common framework to address this gap and introduces new indicators to capture most aspects of port's performance. To the best of our knowledge, import/export/transhipment traffic, container traffic per container berth, liquid bulk traffic per berth, open/warehouse/transit shed area per parcel size, medical expenditure per staff, and CSR contribution as a percentage of total profit are the new indicators in the field of port performance measurement. The unified index: PPI and PPI_{PCA}, developed in this work, evaluate the overall performance to help the decision-making process related to port competitiveness, investment prioritisation, resource utilisation, benchmarking, and revenue administration. However, the proposed PPI should not be overinterpreted beyond its role as a benchmark indicator as it is not a substitute for in-depth port diagnoses. In the later part of this work, the port's efficiency measurement and regression analysis are presented to demonstrate the additional utility of the proposed framework.

Nonetheless, this study has some limitations. Firstly, due to the lack of quantitative data related to dimensions such as safety & security, hinterland connectivity, digitalisation, and other socio-economic factors like knowledge, leadership, training, and education, we could not incorporate these dimensions into our work. Future researchers should include these dimensions to make performance assessments more practical and helpful. The selected indicators for constructing the performance index require data from ports of similar scale and size in terms of business and other infrastructure capabilities, such that the results are comparable in every aspect. Secondly, as per data availability, we have made the pilot assessment year-wise. Month-wise or day-wise, data would aid in making short-term managerial decisions. Thirdly, to simplify the analysis, the framework deployed some indicators irrespective of the type of cargo. For instance, indicators I8-I10 are not necessary for measuring liquid bulk port performance. Therefore, the port authority needs to identify relevant indicators as per the type of ports being considered for the analysis. Future research could also consider developing an adaptive indicator selection framework that accounts for the kind of ports being analysed. Furthermore, researchers can assess the generalisation of the proposed PPI using comparable port data from different regions/countries (like European ports or Chinese ports) to strengthen the validity of the proposed methodology.

Notes

1. CCR model is named after the researchers: Charnes, Cooper, and Rhodes (1978), who introduced the technical efficiency of decision making units (DMUs) based on the constant return to scale assumption.
2. BCC model is named after the researchers: Banker, Charnes, and Cooper (1984), who introduced the pure technical efficiency (PTE) and scale efficiency (SE) of DMUs based on variable return to scale assumption.
3. Scale efficiency = Overall technical efficiency / Pure technical efficiency, or (*SE = OTE / PTE).*

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References

Aksoy, S., and Y. Durmusoglu. 2020. "Improving Competitiveness Level of Turkish Intermodal Ports in the Frame of Green Port Concept: A Case Study." *Maritime Policy & Management* 47 (2): 203–220. doi:10.1080/03088839.2019.1688876.

Aparicio, J., J. F. Monge, and N. Ramón. 2021. "A New Measure of Technical Efficiency in Data Envelopment Analysis Based on the Maximization of Hypervolumes: Benchmarking, Properties and Computational Aspects." *European Journal of Operational Research* 293 (1): 263–275. https://doi.org/10.1016/j.ejor.2020.12.002

Asgari, N., A. Hassani, D. Jones, and H. H. Nguye. 2015. "Sustainability Ranking of the UK Major Ports: Methodology and Case Study." *Transportation Research Part E: Logistics and Transportation Review* 78 (May): 19–39. https://doi.org/10.1016/j.tre.2015.01.014

Banker, R. D., A. Charnes, and W. W. Cooper. 1984. "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis." *Management Science* 30 (9): 1078–1092. doi:10.1287/mnsc.30.9.1078.

Brooks, M. R. 2006. "Chapter 25 Issues in Measuring Port Devolution Program Performance: A Managerial Perspective." *Research in Transportation Economics. Elsevier*. doi:10.1016/S0739-8859(06)17025-0.

Brooks, M. R., and A. A. Pallis. 2008. "Assessing Port Governance Models: Process and Performance Components." *Maritime Policy & Management* 35 (4): 411–432. https://doi.org/10.1080/03088830802215060

Brooks, M. R., T. Schellinck, and A. A. Pallis. 2011. "A Systematic Approach for Evaluating Port Effectiveness." *Maritime Policy & Management* 38 (3): 315–334. https://doi.org/10.1080/03088839.2011.572702

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. "Measuring the Efficiency of Decision Making Units." *European Journal of Operational Research* 2 (6): 429–444. doi:10.1016/0377-2217(78)90138-8.

Chen, J., Z. Wan, F. Zhang, N. K. Park, A. Zheng, and J. Zhao. 2018. "Evaluation and Comparison of the Development Performances of Typical Free Trade Port Zones in China." *Transportation Research Part A: Policy and Practice* 118 (December): 506–526. https://doi.org/10.1016/j.tra.2018.09.009

Chen, Y., D. Yang, P. Lian, Z. Wan, and Y. Yang. 2020. "Will Structure-Environment-Fit Result in Better Port Performance? —an Empirical Test on the Validity of Matching Framework Theory." *Transport Policy* 86: 23–33. doi:10.1016/j.tranpol.2019.12.003.

Chen, L., D. Zhang, M. Xiaojuan, L. Wang, L. Shijian, W. Zhaohui, and G. Pan. 2016. "Container Port Performance Measurement and Comparison Leveraging Ship GPS Traces and Maritime Open Data." *IEEE Transactions on Intelligent Transportation Systems* 17 (5): 1227–1242. https://doi.org/10.1109/TITS.2015.2498409

Chou, C. C. 2007. "A Fuzzy MCDM Method for Solving Marine Transshipment Container Port Selection Problems." *Applied Mathematics and Computation* 186 (1): 435–444. doi:10.1016/j.amc.2006.07.125.

Denktas-Sakar, G., and C. Karatas-Cetin. 2012. "Port Sustainability and Stakeholder Management in Supply Chains: A Framework on Resource Dependence Theory." *Asian Journal of Shipping and Logistics* 28 (3): 301–319. https://doi.org/10.1016/j.ajsl.2013.01.002

Diakomihalis, M., M. I. Kyriakou, and A. Sideris. 2021. "Port Efficiency and the Financial Performance of Greek Public Ports before and during the Economic Crisis." *Maritime Policy & Management* 48 (5): 651–671. https://doi.org/10.1080/03088839.2021.1887528

Geiger, B. C., and G. Kubin. 2012. "Relative Information Loss in the PCA." 2012 IEEE Information Theory Workshop, ITW 562–566. https://doi.org/10.1109/ITW.2012.6404738

Ha, M. H., and Z. Yang. 2017. "Comparative Analysis of Port Performance Indicators: Independency and Interdependency." *Transportation Research Part A: Policy and Practice* 103: 264–278. https://doi.org/10.1016/j.tra.2017.06.013

Ha, M. H., Z. Yang, and J. S. L. Lam. 2019. "Port Performance in Container Transport Logistics: A Multi-Stakeholder Perspective." *Transport Policy* 73: 25–40. https://doi.org/10.1016/j.tranpol.2018.09.021

Ha, M. H., Z. Yang, T. Notteboom, A. K. Y. Ng, and M. W. Heo. 2017. "Revisiting Port Performance Measurement: A Hybrid Multi-Stakeholder Framework for the Modelling of Port Performance Indicators." *Transportation Research Part E: Logistics and Transportation Review* 103: 1–16. https://doi.org/10.1016/j.tre.2017.04.008

Hammarberg, K., M. Kirkman, and S. De Lacey. 2016. "Qualitative Research Methods: When to Use Them and How to Judge Them." *Human Reproduction* 31 (3): 498–501. doi:10.1093/humrep/dev334.

Hossain, N., U. Ibne, F. Nur, R. Jaradat, S. Hosseini, M. Marufuzzaman, S. M. Puryear, and R. K. Buchanan. 2019. "Metrics for Assessing Overall Performance of Inland Waterway Ports: A Bayesian Network Based Approach." Complexity.https://doi.org/10.1155/2019/3518705

Hung, S. W., L. Wen Min, and T. Pao Wang. 2010. "Benchmarking the Operating Efficiency of Asia Container Ports." *European Journal of Operational Research* 203 (3): 706–713. doi:10.1016/j.ejor.2009.09.005.

Jacobs, M. A. 2013. "Complexity: Toward an Empirical Measure." *Technovation* 33 (4–5): 111–118. https://doi.org/10.1016/j.technovation.2013.01.001

Jollife, I. T., and J. Cadima. 2016. "Principal Component Analysis: A Review and Recent Developments." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374: 2065. https://doi.org/10.1098/rsta.2015.0202

Jung, Y. J., and J. M. Casello. 2020. "Assessment of the Transit Ridership Prediction Errors Using AVL/APC Data." *Transportation* 47 (6): 2731–2755. https://doi.org/10.1007/s11116-019-09985-7

Junior, S., G. A. De, A. K. C. Beresford, and S. J. Pettit. 2003. "Liner Shipping Companies and Terminal Operators: Internationalisation or Globalisation?" *Maritime Economics and Logistics* 5 (4): 393–412. https://doi.org/10.1057/palgrave.mel.9100088

K D Shetty and Dwarakish G. (2020). Measuring port performance and productivity. ISH Journal of Hydraulic Engineering, 26(2), 221–227. 10.1080/09715010.2018.1473812

Karamizadeh, S., S. M. Abdullah, A. A. Manaf, M. Zamani, and A. Hooman. 2013. "An Overview of Principal Component Analysis." *Journal of Signal and Information Processing* 4 (3): 173–175. doi:10.4236/jsip.2013.43B031.

Kavilal, E. G., S. Prasanna Venkatesan, and K. D. Harsh Kumar. 2017. "An Integrated Fuzzy Approach for Prioritizing Supply Chain Complexity Drivers of an Indian Mining Equipment Manufacturer." *Resources Policy* 51 (March): 204–218. doi:10.1016/j.resourpol.2016.12.008.

Kuo, K. C., W. M. Lu, and M. H. Le. 2020. "Exploring the Performance and Competitiveness of Vietnam Port Industry Using DEA." *Asian Journal of Shipping and Logistics* 36 (3): 136–144. https://doi.org/10.1016/j.ajsl.2020.01.002

Kutin, N., T. T. Nguyen, and V. Thomas. 2017. "Relative Efficiencies of ASEAN Container Ports Based on Data Envelopment Analysis." *Asian Journal of Shipping and Logistics* 33 (2): 67–77. https://doi.org/10.1016/j.ajsl.2017.06.004

Lagoudis, I. N., I. Theotokas, and D. Broumas. 2017. "A Literature Review of Port Competition Research." *International Journal of Shipping and Transport Logistics* 9 (6): 724–762. https://doi.org/10.1504/IJSTL.2017.086940

Lam, J., and S. Lee. 2015. "Designing A Sustainable Maritime Supply Chain: A Hybrid QFD-ANP Approach." *Transportation Research Part E: Logistics and Transportation Review* 78: 70–81. https://doi.org/10.1016/j.tre.2014.10.003

Lee, P., T. Woo, and Z. Yang. 2018. "Multi-Criteria Decision Making in Maritime Studies and Logistics." *International Series in Operations Research and Management Science* 260: 1–6. https://doi.org/10.1007/978-3-319-62338-2

Lever, J., M. Krzywinski, and N. Altman. 2017. "Points of Significance: Principal Component Analysis." *Nature Methods* 14 (7): 641–642. doi:10.1038/nmeth.4346.

Liu, H. J., P. E. D. Love, M. C. P. Sing, B. Niu, and J. Zhao. 2019. "Conceptual Framework of Life-Cycle Performance Measurement: Ensuring the Resilience of Transport Infrastructure Assets." *Transportation Research Part D: Transport and Environment* 77 (December): 615–626. doi:10.1016/j.trd.2019.10.002.

López-Bermúdez, B., M. J. Freire-Seoane, and D. J. Nieves-Martínez. 2019. "Port Efficiency in Argentina from 2012 to 2017: An Ally for Sustained Economic Growth." Utilities Policy 61. https://doi.org/10.1016/j.jup.2019.100976

Lu, C. S., K. C. Shang, and C. C. Lin. 2016. "Examining Sustainability Performance at Ports: Port Managers' Perspectives on Developing Sustainable Supply Chains." *Maritime Policy & Management* 43 (8): 909–927. https://doi.org/10.1080/03088839.2016.1199918

Molavi, A., G. J. Lim, and B. Race. 2020. "A Framework for Building A Smart Port and Smart Port Index." *International Journal of Sustainable Transportation* 14 (9): 686–700. https://doi.org/10.1080/15568318.2019.1610919

Munim, Z. H., and H.-J. Schramm. 2018. ""The Impacts of Port Infrastructure and Logistics Performance on Economic Growth." *The Mediating Role of Seaborne Trade." Journal of Shipping and Trade* 3: 1. https://doi.org/10.1186/s41072-018-0027-0

Nguyen, H. O., H. Van Nguyen, Y. T. Chang, A. T. H. Chin, and J. Tongzon. 2016. "Measuring Port Efficiency Using Bootstrapped DEA: The Case of Vietnamese Ports." *Maritime Policy & Management* 43 (5): 644–659. https://doi.org/10.1080/03088839.2015.1107922

Park, J., B. K. Lee, and J. M. W. Low. 2020. "A Two-Stage Parallel Network DEA Model for Analyzing the Operational Capability of Container Terminals." *Maritime Policy & Management*. https://doi.org/10.1080/03088839.2020.1859148

Patil, G. R., and G. Sharma. 2020. "Urban Quality of Life: An Assessment and Ranking for Indian Cities." *Transport Policy*. https://doi.org/10.1016/j.tranpol.2020.11.009

Rodrigue, J. P., and T. Notteboom. 2009. "The Terminalization of Supply Chains: Reassessing the Role of Terminals in Port/hinterland Logistical Relationships." *Maritime Policy & Management* 36 (2): 165–183. https://doi.org/10.1080/03088830902861086

Rosa Pires Da Cruz, M., J. J. Ferreira, and S. Garrido Azevedo. 2013. "Key Factors of Seaport Competitiveness Based on the Stakeholder Perspective: An Analytic Hierarchy Process (AHP) Model." *Maritime Economics and Logistics* 15 (4): 416–443. https://doi.org/10.1057/mel.2013.14

Siegel, J., and P. Choudhury. 2012. "A Reexamination of Tunneling and Business Groups: New Data and New Methods." *Review of Financial Studies* 25 (6): 1763–1798. doi:10.1093/rfs/hhs008.

Su, Y., C.-F. Liu, G.-S. Liang, and T.-Y. Chou. 2003. "A Study on Integrated Port Performance Comparison Based on the Concept of Balanced Scorecard." *Journal of the Eastern Asia Society for Transportation Studies* 5: 609–624.

Suárez-Alemán, A., J. M. Sarriera, T. Serebrisky, and L. Trujillo. 2016. "When It Comes to Container Port Efficiency, are All Developing Regions Equal?" *Transportation Research Part A: Policy and Practice* 86 (April): 56–77. https://doi.org/10.1016/j.tra.2016.01.018

Tongzon, J. L. 2009. "Port Choice and Freight Forwarders." *Transportation Research Part E: Logistics and Transportation Review* 45 (1): 186–195. https://doi.org/10.1016/j.tre.2008.02.004

UNCTAD. 1985. "Operations Planning in Ports." *Monographs on Port Management*.

UNCTAD. 2016. "Port Management: Linking Performance Indicators to Strategic Objectives." *United Nations Conference on Trade and Development* 15 (9): 46. https://doi.org/10.1057/9781137475770

Vaggelas G K. (2019). Measurement of port performance from users' perspective. MABR, 4(2), 130–150. 10.1108/MABR-08-2018-0024

Wiegmans, B., P. Witte, and T. Spit. 2015. "Characteristics of European Inland Ports: A Statistical Analysis of Inland Waterway Port Development in Dutch Municipalities." *Transportation Research Part A: Policy and Practice* 78 (August): 566–577. https://doi.org/10.1016/j.tra.2015.07.004

Woo, S. H., S. Pettit, A. Beresford, and D. Wook Kwak. 2012. "Seaport Research: A Decadal Analysis of Trends and Themes Since the 1980s." *Transport Reviews*. doi:10.1080/01441647.2012.660996.

Appendices

Web link to other supporting files for this manuscript.

Appendix A. https://drive.google.com/file/d/1TfQoS0sdCpMy8JXboT6bYDv4xjK1fwpn/view?usp=sharing
Appendix B. https://drive.google.com/file/d/1_QJCLBKX-dhwygK0M_eC0qs4B3ipsZXi/view?usp=sharing
Appendix C. https://drive.google.com/file/d/1taWg1sN52V5l9zyiZeiYRQwwWMgpJ23Q/view?usp=sharing
Appendix D. https://drive.google.com/file/d/1N3_QGjrvoCmMTLpHHV_YZ-jTqO2DmKlP/view?usp=sharing
Dataset: https://drive.google.com/file/d/140Uq0ED703EWGuwUal-oApZGCWQcnnjo/view?usp=sharing

Appendix A.

Definitions of port performance indicators.

PPIs	Units	Definitions	Formulae
Operation indicators			
Average berth occupancy	Percent	Berth occupancy is the ratio of time the berth is occupied by a vessel to the total time available in that period.	-
Average output per ship-berth-day	Tonnes	It is the average volume of cargo handled per day per vessel at each berth in port. It is generally used to measure ports' productivity.	-
Average parcel size	Tonnes	It is the average amount of cargo carried by each vessel	(Total traffic)/(Total vessel handled)
Average turnaround time per ton cargo	Hours per ton	Turnaround time indicates the average time spent (in days) by a ship from its entry into the port till its departure.	(Average turnaround time*24*Total vessel handled)/(Average parcel size)
Berth throughput	x000 Tonnes	It is the cargo handling capacity of the berth	(Total traffic)/(number of berths)
Container cargo traffic per berth	x000 Tonnes	It is the total amount of container cargo handled at container handling berths	(Total container traffic)/(number of container berths)
Liquid bulk cargo traffic per berth	x000 Tonnes	It is the total amount of liquid bulk cargo handled at liquid bulk cargo handling berths	(Total liquid bulk)/(number of liquid bulk berths)
Other cargo traffic per berth	x000 Tonnes	It is the total amount of dry & break bulk cargo handled at dry/break/general cargo handling berths	(Total other cargo traffic)/(number of other cargo berths)
Idle time to total time at berth	Percent	It is the amount of total time at berth remaining unutilized as Idle time.	-
Idle time to total time at port	Percent	It is the amount of total time at port remaining unutilized as Idle time.	-
Staff strength per thousand ton cargo	Numbers	It is the number of employees engaged to handle per metric ton of cargo.	(Total staff strength)/(Total traffic)
Total export traffic ratio	Percent	It is the percent of export traffic handled at the port.	(Total export traffic*100)/(Total traffic)
Total import traffic ratio	Percent	It is the percent of import traffic handled at the port.	(Total import traffic*100)/(Total traffic)
Total vessel handled	Numbers	It is the number of ships handled at the port annually.	
Physical infrastructure indicators			
Entrance channel minimum width	Meters	It is the minimum width available at the entry channel.	-
Entrance channel minimum depth	Meters	It is the minimum depth available at the entry channel.	-
Number of container berths	Numbers	The number of berths available in a port to handle container cargo.	-
Number of liquid bulk berths	Numbers	The number of berths available in a port to handle liquid bulk cargo.	-
Number of other cargo berths	Numbers	The number of berths available in a port to handle dry and break bulk cargo.	-
Area of open space per parcel size	Square meters per ton	Area of available open space to store tranship containers, empty containers, trucks, and equipment parking.	(Area of open space)/(Average parcel size)

(*Continued*)

PPIs	Units	Definitions	Formulae
Area of warehouse per parcel size	Square meters per ton	Area of available warehouse space to store general cargo, perishable products, cement silos, electronic products, etc.	(Area of warehouse)/ (Average parcel size)
Area of transit shed per parcel size	Square meters per ton	Area of transit sheds to facilitate the loading and discharge of goods especially operated by railways and roadways. It is meant for short-term storage purposes.	(Area of transit sheds)/ (Average parcel size)
Technical infrastructure indicators			
Total forklifts available	Numbers	It is the total number of functioning forklifts of different capacities in the port.	-
Total wharf cranes available	Numbers	It is the total number of functioning wharf cranes in the port.	-
Total mobile cranes available	Numbers	It is the total number of functioning mobile cranes in the port.	-
Other equipment (payloader, dozers, tractors, trailers, locomotives)	Numbers	It is the total number of functioning other equipment in the port.	-
Financial indicators			
Administration expenditure ratio	Percent	Percent of operating income expenditure on general management and administration like maintaining IT-related resources, Accounting & Auditing, and legal proceedings.	(Administration expenditure *100)/ (Operating income)
Security expenditure ratio	Percent	Percent of operating income expend on maintaining safer practices and providing security against theft and other damages.	(Security expenditure *100)/ (Operating income)
Operation and maintenance expenditure ratio	Percent	Percent of operating income expend on operating and maintaining the machines and equipment, and other berths facilities to enable smooth handling operations.	(O&M expenditure *100)/ (Operating income)
Depreciation expenditure ratio	Percent	Percent of operating income expend as depreciation and amortization	(Depreciation and amortization cost *100)/ (Operating income)
Store expenditure ratio	Percent	Percent of operating income expend in maintaining the inventory of equipment's and other resources	(Store expenditure *100)/ (Operating income)
Finances and miscellaneous expenditure ratio	Percent	Percent of operating income expend in bank charges, pensions to employee, employee leaves encashment, etc.	(Miscellaneous expenditure *100)/ (Operating income)
Operating ratio	Percent	It is the ratio of operating expenses to operating income. It shows the efficiency of the company's management.	(Operating expenditure *100)/ (Operating income)
Gross profit margin	Percent	It is the ratio of operating surplus to operating income. It shows the efficiency of the company's management.	(Operating income- Operating expenditure)/ (Operating Income)

(*Continued*)

PPIs	Units	Definitions	Formulae
Capital employed	Million Rupees	Capital employed represents net fixed assets plus the working capital	-
Operating income per ton cargo	million Rupees per ton	It is the revenue generated by port operations per metric ton of cargo handled	(Operating income *1000)/(Total traffic)
Net Profit per ton cargo	Rupees	It is the net profit generated by port operations by carrying per metric ton of cargo.	(Total income—Total expenditure) * 1000/(Total traffic)
Socio-economic indicators			
Medical expenditure per staff	Rupees per employee	It is the amount of average revenue expenditure in meeting the medical requirements of each staff members	(Medical expenditure)/(staff strength)
Salary expenditure per staff	Rupees per employee	It is the amount of average revenue expend in providing salaries to each staff members	(Salary expenditure)/(staff strength)
CSR expenditure ratio	Percent	It is the ratio of the amount of average revenue expand in corporate social responsibility (CSR) and Net profit	(CSR expenditure)/(Net profit)

Appendix B.

Ranking of ports as per PPI score (category-wise).

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI	Rank	Port name	Year	PPI	Rank	Port name	Year	PPI	Rank
JNPT	2015	151	1	Kandla	2016	130	1	Paradip	2013	130	1
JNPT	2013	146	2	Kandla	2017	130	2	Kandla	2016	129	2
JNPT	2014	146	3	Paradip	2015	124	3	Paradip	2016	128	3
JNPT	2016	144	4	Paradip	2013	123	4	Kandla	2017	127	4
JNPT	2017	143	5	Paradip	2016	123	5	Paradip	2014	125	5
JNPT	2012	142	6	Paradip	2017	122	6	Paradip	2015	125	6
Chennai	2012	118	7	Kandla	2015	120	7	Paradip	2012	124	7
Chennai	2014	111	8	Paradip	2012	119	8	Paradip	2017	122	8
VOC Tuticorin	2014	111	9	Paradip	2014	119	9	Kandla	2015	119	9
VOC Tuticorin	2015	111	10	Kandla	2012	118	10	Kandla	2012	117	10
Chennai	2013	110	11	Chennai	2012	117	11	VOC Tuticorin	2014	113	11
Chennai	2015	110	12	Kandla	2014	114	12	Vishakhapatnam	2013	112	12
VOC Tuticorin	2016	109	13	Chennai	2013	113	13	VOC Tuticorin	2015	111	13
Chennai	2017	108	14	Chennai	2016	112	14	Kandla	2014	109	14
Chennai	2016	107	15	Mumbai	2013	112	15	VOC Tuticorin	2013	109	15
VOC Tuticorin	2013	105	16	Vishakhapatnam	2014	112	16	Vishakhapatnam	2012	109	16
Vishakhapatnam	2012	105	17	Chennai	2015	111	17	VOC Tuticorin	2012	108	17
VOC Tuticorin	2012	104	18	Kandla	2013	111	18	Kandla	2013	107	18
VOC Tuticorin	2017	104	19	Chennai	2014	110	19	VOC Tuticorin	2016	107	19
Vishakhapatnam	2013	104	20	Vishakhapatnam	2013	110	20	Vishakhapatnam	2014	106	20

(*Continued*)

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI	Rank	Port name	Year	PPI	Rank	Port name	Year	PPI	Rank
Vishakhapatnam	2017	104	21	Vishakhapatnam	2015	110	21	Vishakhapatnam	2015	105	21
Kolkata	2013	102	22	New Mangalore	2013	109	22	Vishakhapatnam	2017	105	22
Kolkata	2016	100	23	Mumbai	2012	108	23	New Mangalore	2012	104	23
Vishakhapatnam	2014	99	24	Mumbai	2014	108	24	New Mangalore	2013	102	24
Vishakhapatnam	2016	97	25	Mumbai	2015	108	25	New Mangalore	2014	102	25
Kolkata	2012	96	26	New Mangalore	2012	108	26	VOC Tuticorin	2017	101	26
Kolkata	2014	96	27	New Mangalore	2014	107	27	Mormugao	2017	100	27
Kolkata	2015	96	28	Vishakhapatnam	2012	107	28	Vishakhapatnam	2016	100	28
Kolkata	2017	95	29	Vishakhapatnam	2017	105	29	Mormugao	2015	99	29
Cochin	2017	94	30	Chennai	2017	103	30	Mormugao	2016	95	30
Vishakhapatnam	2015	94	31	Mumbai	2017	103	31	Mormugao	2014	93	31
Cochin	2016	92	32	Vishakhapatnam	2016	103	32	New Mangalore	2017	91	32
Cochin	2013	85	33	Mumbai	2016	100	33	Mormugao	2013	89	33
Cochin	2012	84	34	New Mangalore	2017	100	34	Mormugao	2012	87	34
Cochin	2015	83	35	New Mangalore	2015	99	35	New Mangalore	2015	87	35
Cochin	2014	82	36	New Mangalore	2016	98	36	New Mangalore	2016	87	36
				Cochin	2017	96	37				
				Cochin	2016	93	38				
				Cochin	2015	90	39				
				Cochin	2013	88	40				
				Cochin	2014	86	41				
				Cochin	2012	84	42				

Appendix C.

Ranking of ports as per PPI_{PCA} score (category-wise).

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank
JNPT	2015	31.89	1	Kandla	2017	20.50	1	VOC Tuticorin	2014	23.98	1
JNPT	2014	31.36	2	Kandla	2016	19.80	2	Paradip	2016	23.13	2
JNPT	2013	30.89	3	Kandla	2015	19.52	3	Kandla	2016	22.70	3
JNPT	2016	30.74	4	Paradip	2016	19.50	4	Paradip	2013	22.59	4
JNPT	2012	29.85	5	Paradip	2017	19.47	5	Kandla	2017	22.51	5
JNPT	2017	29.67	6	Chennai	2013	19.35	6	Paradip	2017	22.48	6
Chennai	2012	26.35	7	Mumbai	2012	19.25	7	Paradip	2015	22.24	7
Chennai	2014	25.02	8	Chennai	2016	19.18	8	VOC Tuticorin	2013	21.99	8
Chennai	2013	24.98	9	Kandla	2014	19.04	9	VOC Tuticorin	2012	21.94	9
Chennai	2017	24.84	10	Chennai	2012	18.97	10	VOC Tuticorin	2015	21.86	10
Chennai	2015	24.73	11	Mumbai	2013	18.91	11	Paradip	2012	21.62	11
VOC Tuticorin	2015	24.66	12	Paradip	2015	18.85	12	VOC Tuticorin	2016	21.48	12
VOC Tuticorin	2016	24.03	13	Kandla	2013	18.81	13	Paradip	2014	21.44	13
VOC Tuticorin	2014	23.95	14	Paradip	2013	18.61	14	Kandla	2015	20.95	14
Chennai	2016	23.84	15	Mumbai	2014	18.53	15	VOC Tuticorin	2017	20.67	15
Vishakhapatnam	2012	23.77	16	Kandla	2012	18.44	16	Kandla	2012	20.43	16
Vishakhapatnam	2017	23.38	17	Mumbai	2015	18.35	17	New Mangalore	2013	19.92	17
Vishakhapatnam	2013	22.98	18	Chennai	2015	18.28	18	New Mangalore	2012	19.87	18
VOC Tuticorin	2013	22.68	19	Paradip	2012	18.19	19	Vishakhapatnam	2013	19.68	19
Vishakhapatnam	2014	22.28	20	Vishakhapatnam	2014	18.14	20	Vishakhapatnam	2015	19.22	20
VOC Tuticorin	2017	22.25	21	Vishakhapatnam	2015	18.13	21	Vishakhapatnam	2012	18.88	21
VOC Tuticorin	2012	22.25	22	Mumbai	2017	18.03	22	New Mangalore	2014	18.80	22
Vishakhapatnam	2016	21.96	23	Chennai	2014	17.96	23	Kandla	2014	18.79	23
Cochin	2017	21.25	24	Vishakhapatnam	2013	17.92	24	Vishakhapatnam	2017	18.25	24
Kolkata	2013	21.03	25	Vishakhapatnam	2012	17.88	25	Vishakhapatnam	2014	18.15	25
Vishakhapatnam	2015	20.85	26	Chennai	2017	17.76	26	Vishakhapatnam	2016	17.74	26
Cochin	2016	20.48	27	New Mangalore	2014	17.75	27	Kandla	2013	17.72	27
Kolkata	2016	20.41	28	Paradip	2014	17.55	28	New Mangalore	2017	16.26	28
Kolkata	2012	19.82	29	New Mangalore	2013	17.53	29	New Mangalore	2016	15.96	29
Kolkata	2017	19.77	30	Mumbai	2016	17.28	30	Mormugao	2014	15.90	30
Kolkata	2015	19.67	31	New Mangalore	2012	17.24	31	Mormugao	2015	15.82	31

(*Continued*)

Container ports				Liquid bulk ports				Other cargo ports			
Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank	Port name	Year	PPI_{PCA}	Rank
Cochin	2012	19.66	32	New Mangalore	2017	17.21	32	New Mangalore	2015	15.56	32
Kolkata	2014	19.34	33	Vishakhapatnam	2016	16.85	33	Mormugao	2017	15.48	33
Cochin	2013	19.29	34	New Mangalore	2015	16.71	34	Mormugao	2013	15.03	34
Cochin	2015	19.16	35	New Mangalore	2016	16.36	35	Mormugao	2016	14.64	35
Cochin	2014	19.01	36	Vishakhapatnam	2017	16.20	36	Mormugao	2012	14.20	36
				Cochin	2016	15.52	37				
				Cochin	2015	15.32	38				
				Cochin	2017	15.31	39				
				Cochin	2013	14.86	40				
				Cochin	2012	14.83	41				
				Cochin	2014	14.73	42				

Appendix D.

DEA results for liquid bulk and other cargo ports.

DEA results for liquid bulk ports			
DMUs Port name (year)	Pure Technical Efficiency (PTE)	Overall Technical Efficiency (OTE)	Scale Efficiency (SE)
Chennai (2012)	91.6	90.5	98.8
Chennai (2013)	85.1	74.6	87.6
Chennai (2014)	89.4	83.3	93.1
Chennai (2015)	85.7	77.0	89.8
Chennai (2016)	82.2	69.0	84.0
Chennai (2017)	85.3	70.2	82.3
Cochin (2012)	**100.0**	57.8	57.8
Cochin (2013)	**100.0**	76.1	76.1
Cochin (2014)	**100.0**	77.9	77.9
Cochin (2015)	**100.0**	78.1	78.1
Cochin (2016)	**100.0**	87.5	87.5
Cochin (2017)	**100.0**	**100.0**	**100.0**
Kandla (2012)	93.5	92.1	98.5
Kandla (2013)	88.0	68.0	77.3
Kandla (2014)	85.8	76.7	89.4
Kandla (2015)	86.8	83.4	96.1
Kandla (2016)	**100.0**	**100.0**	**100.0**
Kandla (2017)	92.6	90.8	98.0
Mumbai (2012)	95.6	82.6	86.4
Mumbai (2013)	**100.0**	**100.0**	**100.0**
Mumbai (2014)	**100.0**	94.4	94.4
Mumbai (2015)	**100.0**	**100.0**	**100.0**
Mumbai (2016)	**100.0**	**100.0**	**100.0**
Mumbai (2017)	94.6	88.6	93.7
New Mangalore (2012)	**100.0**	**100.0**	**100.0**
New Mangalore (2013)	**100.0**	**100.0**	**100.0**
New Mangalore (2014)	**100.0**	83.2	83.2
New Mangalore (2015)	**100.0**	78.3	78.3
New Mangalore (2016)	**100.0**	84.3	84.3
New Mangalore (2017)	96.5	74.9	77.7
Paradip (2012)	95.7	91.2	95.4
Paradip (2013)	95.7	95.4	99.7
Paradip (2014)	**100.0**	**100.0**	**100.0**
Paradip (2015)	98.1	97.7	99.6
Paradip (2016)	91.7	85.5	93.3
Paradip (2017)	91.7	88.3	96.3
Vishakhapatnam (2012)	91.7	73.9	80.6
Vishakhapatnam (2013)	92.8	84.7	91.2
Vishakhapatnam (2014)	91.9	85.7	93.2
Vishakhapatnam (2015)	91.5	82.3	89.9
Vishakhapatnam (2016)	98.3	83.9	85.3

(*Continued*)

DEA results for liquid bulk ports			
Vishakhapatnam (2017)	**100.0**	98.1	98.1

DEA results for other cargo ports (dry and break bulk)

DMUs Port name (year)	Pure Technical Efficiency (PTE)	Overall Technical Efficiency (OTE)	Scale Efficiency (SE)
Kandla (2012)	98.7	88.7	89.8
Kandla (2013)	89.2	58.2	65.3
Kandla (2014)	76.4	50.6	66.3
Kandla (2015)	73.6	59.2	80.4
Kandla (2016)	**100.0**	**100.0**	**100.0**
Kandla (2017)	84.9	83.3	98.1
Mormugao (2012)	90.7	39.9	43.9
Mormugao (2013)	93.7	50.4	53.7
Mormugao (2014)	93.7	50.4	53.7
Mormugao (2015)	**100.0**	97.8	97.8
Mormugao (2016)	**100.0**	83.3	83.3
Mormugao (2017)	90.4	46.1	51.0
New Mangalore (2012)	**100.0**	78.3	78.3
New Mangalore (2013)	**100.0**	71.6	71.6
New Mangalore (2014)	**100.0**	63.2	63.2
New Mangalore (2015)	**100.0**	48.3	48.3
New Mangalore (2016)	**100.0**	51.0	51.0
New Mangalore (2017)	**100.0**	47.1	47.1
Paradip (2012)	82.5	77.5	93.9
Paradip (2012)	**100.0**	**100.0**	**100.0**
Paradip (2013)	**100.0**	97.3	97.3
Paradip (2014)	78.8	73.6	93.4
Paradip (2015)	66.3	56.1	84.6
Paradip (2016)	70.2	60.2	85.8
VOC Tuticorin (2012)	**100.0**	92.7	92.7
VOC Tuticorin (2013)	**100.0**	85.0	85.0
VOC Tuticorin (2014)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2015)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2016)	**100.0**	**100.0**	**100.0**
VOC Tuticorin (2017)	**100.0**	**100.0**	**100.0**
Vishakhapatnam (2012)	78.9	46.6	59.0
Vishakhapatnam (2013)	80.9	61.1	75.5
Vishakhapatnam (2014)	90.5	73.4	81.1
Vishakhapatnam (2015)	97.4	73.9	75.8
Vishakhapatnam (2016)	93.8	59.6	63.5
Vishakhapatnam (2017)	**100.0**	**100.0**	**100.0**