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Multi-dimensional Assessment of Port Performance: A Composite measure

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ABSTRACT

Existing methods of port performance considering multi-criteria goals, system boundaries, subsystems, and components involving a set of assumptions have limitations and may even give contradictory results. The paper proposes the overall port performance index (OPPI) as a geometric aggregation of the ratios of indicators at a given period over a base period without considering the performance of other ports. The index also provides performance in each of the chosen dimensions, the identification of critical dimensions or indicators requiring managerial attention and quantifying the relative importance and contribution of each dimension/indicator. Replacing the base period vector with the vector for the previous year will indicate an improvement/decline of OPPI on a year-to-year basis. The proposed index avoiding scaling and weights satisfies desired properties of measurements like monotonically increasing, time-reversal test, formation of chain indices, statistical testing and estimation of population parameters. The chain indices find the growth of OPPI across time. The coefficient of variation of the index indicates growth consistency. The empirical illustration shows that the index improved for each Major Port in India in 2017 from 2012. However, the consistency of growth of OPPI varied amongst the ports. The method can be applied even for skewed data and enables additional dimensions and indicators to be included.

1. Introduction.

Seaports provide various services and functions and produce multiple outputs. Several factors influence a port's efficiency and the maritime traffic of a country. Port inefficiencies are reflected by longer dwell time of cargo and ships, interrupted vessel movements, complex documentations, lower container moves per crane hour, higher emission of greenhouse gases (GHG) per ton of goods, etc.(Kahyarara, 2020).The impact of port performance on trade has been investigated (UNCTAD 2020). A strong relationship between port efficiency and factors of production and profitability of the port indicates the factors influencing higher output, income, and employment (Park and De, 2004). Improved efficiency also helps ports to have a better image in the market and influence their business. A port aims at fulfilling stakeholders' needs and identifying areas of improvement, considering different dimensions and interacting subsystems of port performance. However, the objectives of various departments/wings of a port may vary. Therefore, ports must have an overall port performance index (OPPI) satisfying these objectives and considering multi-criteria goals, system boundaries, subsystems, and components.

Port performance involves a finite set of interrelated measures relating to vessels' stay at port, loading/unloading/rate of cargo, quality storage/inland transport, etc. (Dayananda and Dwaraksh, 2020). Ports improving their efficiency from the 25th to 75th percentile reduced handling and shipping costs by around 12 %, implying an increase in bilateral trade by approximately 25 % (Clark et al. 2004). Port productivity may be referred to as 'Total Factor Productivity' (TFP), involving all factors of production (Coelli et al.2005). Efficiency could be conceptualized as the relative productivity over a given time, within or amongst ports (Wang et al. 2002).

Port performance involves several dimensions/domains, each containing a finite number of indicators (independent or interre-

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lated) that differ in measurement methods, units, nature of scale (ordinal or ratio scale), shape and form of distributions. Dimensions of multi-dimensional port performance have changed due to changing roles of ports to their stakeholders, the replacement of local competition by global competition, etc. (Bucak et al. 2020). Port efficiency measurements are not strictly comparable as they differ in theoretical approaches, different time-frames, ports belonging to other countries, and diverse activities analysed (Gonzalez and Trujillo (2009). Woo et al. (2012) reviewed ports studies from 1980 to 2009 and opined that the development of theories and methodologies should guide the future of ports research.

Turn round time (TAT) is often considered as the key performance indicator (KPI) of ports which requires attention from the perspectives of the trade, shipping lines and stakeholders. Other crucial indicators include turn round time times of inland carriers and dwell time of cargo. But, TAT cannot be taken as the single indicator to assess the performance of ports even if shipping lines demand a lower TAT for the choice of ports which ultimately impacts trade (Sinha & Roy Chowdhury, 2022).TAT may vary for different sizes of vessels and cargo load per vessel. Bigger-sized ships with higher parcel loads can be served with more crane capacity than vessels of smaller dimensions (Handy-max or Supra-max) and can influence TAT in different fashions. Ports can only be compared in terms of TAT when the sizes of vessels calling at ports are similar.

Traffic handled by ports is commonly used to reflect the functioning of ports (Lee and Bachmann, 2020; United States Department of Transportation, 2021). An increase in port cargo throughput is deemed to be a growth indicator. However, cargo can increase with increased economic growth and the absence of alternate ports. As such, cargo throughput is an economic indicator. However, cargo volume alone cannot reflect gains from trade or improvement in total factor productivity or GDP growth (Lakshmanan,2011).

An overall indicator of the port's performance should ensure meaningful comparison across time and with other ports. Thus, at a point in time, a port may rank low compared to another (a hub-port) but yet be competitive in terms of year-on-year growth of cargo or revenue or a combination of several measures of physical and financial efficiency parameters.

Reliability in logistics services by its providers serves as a determinant of logistics quality (Dua and Sinha, 2019; Dua et al., 2023). Service reliability is deemed as the single outcome dimension of service transactions and crucial to service choices (Zeithaml et al. 2009). Thus, port service reliability may be considered a composite measure in a continuous evaluation platform.

The paper proposes a single-valued overall-port-performance-index (OPPI) to reflect the overall performance of a port at a given period without considering the performance of other ports. It facilitates meaningful comparisons satisfying the following properties:

1. Continuous and monotonically increasing (marginal increase in an indicator will increase OPPI).
2. Reduction of substitutability among the component indicators (higher value of an indicator should not compensate the lower value of another indicator).
3. Minimize or avoid outliers (to avoid bias for developed or under-developed ports).
4. Satisfies time-reversal test, i.e. $OPPI_{t0}.OPPI_{ot} = 1$ where t denotes the current period and 0 denotes the base period.
5. Facilitates formation of chain indices, i.e. $OPPI_{20} = OPPI_{21}.OPPI_{10}$.
6. Facilitates estimation of population OPPI for a sample of ports of a country.

The proposed OPPI in terms of selected performance domains is illustrated using data from Major Indian Ports under the control of the Union government along with the growth of OPPI of a seaport over time, consistency of growth, and identification of port-wise key areas, requiring managerial attention.

2. Literature review.

Measures based on a single indicator like cargo throughput or TAT are not adequate for effective comparison of ports and may even give contradictory results. For example, lower TAT is perceived as the key performance indicator (KPI). TAT of a vessel in a port is the summation of transit time, waiting time, docking and undocking time, idle and working time at berth. TAT depends on different combinations of vessel size and parcel load. Bigger-sized ships with larger parcel loads allow increased (in capacity and number) crane deployment compared to smaller vessels and can influence TAT in different fashions, as demonstrated in Table 1.

Table 1 illustrates that ports handling predominantly Panamax and Capsize vessels with higher parcel loads can experience higher TAT and increase traffic; thus, qualify as better ports than a port with lower TAT. Hence, TAT per ton/TEU merits consideration.

Though the cranes and equipment may be similar for a particular type of cargo, operational efficiencies may vary with the age profile of the equipment. Repairable port equipment with long economic life exhibits bathtub curve performance (Keskinen et al., 2017) and differs in efficiency over time. Hence, comparing ports based on TAT only in the absence of ship sizes, age profile of equipment, physical-condition data, and synchronization of gate and yard operations may not be appropriate.

Parcel load (load per vessel) is a crucial determinant of port productivity (Sinha & Roy Chowdhury, 2022). Parcel load with higher productivity reduces stay-time of ships at berths and TAT and minimizes cost and fuel consumption. Higher parcel load reduces the number of vessels calling at the port, emissions and power consumption.

Chen et al. (2020) related port performance to management structure, geographic factors, socio-economic environment of ports, and local supply chain systems. Tongzon & Heng (2005) suggested a port-competitiveness-index (PCI) considering objective factors (port efficiency, cost, landside accessibility, draft availability) and perception-based factors (reliability, preferences, and product differentiation). The significant limitations of PCI are:

Table 1: TAT for different dimensions of vessels.

Vessel type	Length (Meters)	Width (Meters)	Quay cranes Outreach in containers per vessel	Max. Parcel Load (TEUs)	Number of quay cranes per vessel	Ideal TAT with 60 moves per hour
Panamax	289.56	32.31	≤16 across	5000	4	32
Intermediate-size	366	51.25	17-19 across	8000	5	34
Suezmax or Post-Panamax	400	50	20-23 across	12000	6	43

Source: Adapted from: https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/port-performance/218601/figure-2-1-vessel-size-and-corresponding-port-infrastructure.pdf and http://www.liftech.net/wp-content/uploads/2002/11/Quay-Crane-Productivity-Paper.pdf.

1. Measuring stakeholders' perceptions in ordinal scale with limitations in arithmetic aggregation and difficulties in monitoring.
2. Does not consider financial efficiency and sustainability efficiency.
3. Lacks appropriate methods of combining ordinal data and ratio/interval scale data.

2.1. *Domains of efficiency:*

Operational level: This level comprises infrastructural facilities, investments made and returns thereof, outputs, productivity, issues relating to the supply chain, and relevant port productivity indicators.

A domain can have several sub-domains like measures of *outcome* (cargo throughput, TAT, operating income / expenditure), estimates of *productivity* (bottlenecks on efficient handling of cargo and ships, adequacy of berths, cranes, a system of aggregation/evacuation of cargo, synchronization of operations at gates/yard and berth); *logistics* (issues relating to supply-chain, hinterland connectivity and response time);*external domains* (economic activities of the hinterland, competition with neighbouring ports, rules and restrictions).

2.2. *Stakeholders' preference:*

Ordinal data is obtained through opinion/preference surveys using Likert/Rating scale with varying number of response-categories per item. Stakeholders like Shipping Lines, Importers & Exporters, Customs House Agents, freight forwarders, the Government, and others differ in their objectives. Thus, their criteria for preference or selection of a port also differ. Other factors influencing a port's choice include port charges, terminal handling charges, first / last port of call, maritime and inland transit time, number of inland transport operators, etc.

2.3. *Environmental and ecological perspectives:*

Relevant indicators in ports cover emission of NO_x, SO_x, CO_2; energy consumed per ton cargo handled; ballast water and environmental discharges; anti-erosion and anti-fouling for hull; anti-pollution and sewage treatment for harbours/docks, oily water; sanitary sewage; industrial waste-water and chemicals; monitoring of biophysical and marine environmental data, etc. Data on the selected indicators are in different units, and the combined efficiency index depends heavily on the aggregation method. However, cut-off scores or threshold values are available at the national level for most environmental indicators.

3. Stages of construction of Overall Port Performance Index.

1. Selection of domains and indicators within a domain.
2. Scaling or normalization of indicators.
3. Aggregating the indicators to get domain scores and OPPI for a Port.

Researchers lack consensus regarding the indicators' selection, normalisation, and aggregation methods.

3.1. *Selection of domains and indicators.*

The selection of indicators is primarily based on port efficiency determinants, policy variables, regulations at seaports, and availability of reliable data. Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) approaches to assess seaport efficiencies have no uniformity in the output considered (Gonza'lez and Trujillo, 2008). Choice of variables can significantly influence the efficiency scores from DEA**.** Liu (1995) considered income generated from the ports, number of ships, freight movement, gross tonnage, market share, break-bulk cargo, containerized cargo, roll-on/roll-off traffic, dry bulk, liquid bulk, and net income. Marlow & Paixão (2002) suggested internal and external performance indicators for lean port performance measurement. Notteboom & Rodrigue (2005) used supply-chain management approach to port operations where indicators differed from conventional port performance measures. However, multicollinearity exists among such input variables due to high correlations implying double counting. Lozano (2009) used Malmquist productivity index to monitor performance trends which is sensitive to input and output variables. ESPO (2012) suggested five domains: Market Trends and Structure (Maritime Traffic, Vessel Traffic); Socio-Economic Impact (Employment, Added value); Environmental Performance (Carbon Footprint, Waste Management, Water Consumption, Environmental Management Systems); Logistic Chain and Operational

Performance (Rail–Road-IWT connectivity, customs procedures); Governance (Integration of port cluster, corporate and social responsibility, autonomous management). Patrick et al. (2022) evaluated port performance and selection criteria based on Physical Internet (PI), which is a paradigm-changing and technology-driven vision, using weighted sum where weights were found by Bayesian Best-Worst Method. However, development of freight transport and logistics (FTL) systems based on PI approach may result in uncertainty for its stakeholders like ports.

A lack of uniformity in the definition and computation of indicators is also observed. Tongzon (2001)considered workers under port authorities that do not participate in cargo handling as an approximation to assess the workers involved in cargo operations. Martin (2002) considered the stevedore workers loading and unloading to/from ships and the port workers on shore. Similarly, for generated income, Liu (1995) considered the amounts received from third parties related to the port services, excluding revenue from the sale of goods; Martínez-Budría et al. (1999) also used this approach to define one of the multi-output vector components for containers.

Indicators like TAT, PBD, idle time percentage, operating expenditure, etc., are negatively related to performance, where a lower value indicates better performance. For such an indicator (X), usual practice is to take reciprocal or use transformation $Z = 1 - \frac{X - X_{Min}}{X_{Max} - X_{Min}}$. However, such transformation changes the distribution of the transformed scores and may impact the final index.

Partial Productivity indicators (PPIs) in percentages are not meaningful for averaging. Addition of percentages may give wrong figures if denominators $D_i \neq KD_j\ \forall\ i \neq j$.

Subjective indicators like efficient Customs service, Port reputation, Satisfaction with terminal operations are measured through Likert questionnaire. Combining such ordinal scores with indicators in ratio scale like Port charges, number of berths / terminals, output per ship-berth-day, TAT, etc., requires prior conversion of ordinal data. Major problems with Likert data are:

- Non-satisfaction of equidistance property, which implies non-admissibility of addition.

- Equal importance to the items despite different values of inter-item correlations, item-total correlations, different factor loadings, etc., is not justified.

- Fails to discriminate the respondents with tied scores.

- Distribution of item scores and test scores are different and often found to be skewed

- Scales using 4-point, 5-point, and 7-point Likert items differ in mean, standard deviation (SD),shape and form of distribution, influencing item/test parameters more by the number of levels than the underlying variable (Lim, 2007). Reliability, validity, and discriminating power differ for K-point scales (K= 3, 4, 5. . . .) (Preston and Colman, 2000).

Selection of indicators should depend on the purpose. However, admissibility of mathematical operations on the selected indicators needs to be considered. Variable selection bias, inferences' reliability, may be minimized if an indicator's ratio is considered at two different periods.

3.2. Scaling / Normalization.

Scaling is done primarily to have unit-free data, preferably with common distribution and desired score range. Popular normalization methods are:

i) Min.-Max transformation: $Z = \frac{X - X_{Min}}{X_{Max} - X_{Min}}$ where $Z \in [0, 1]$ and reflects the performance of a port relative to other ports (Rezaei, 2018). It depends on the extreme values (unreliable outliers). A port may get an improved Z-score in a subsequent period exclusively due to the poor performance of other ports. $\frac{\text{Gain in Z}}{\text{unit increase in X}}$ is different at different values of X.

ii) Standardizing:$Z = \frac{X - \text{Mean}(X)}{\text{SD}(X)}$ ~N(0,1)with$-\infty < Z < \infty$ (Dasgupta and Sinha, 2016). Normally distributed Z-score can be converted to avoid negative values by a linear transformation.

iii) $Z_i = \frac{X_i}{\bar{X}} \times 100$. It is affected by the change of origin.

iv) $Z_i = \frac{X_i}{X_{Max}} \times 100$. This again depends on $X_{Max}$and reflects relative score and not absolute measurement; thus, comparing two ports may not be meaningful.

v) For longitudinal data, standardization of score of i-th port: $Y_i^t = \frac{X_i^t - X_i^{t-1}}{X_i^t}$ where t denotes period. This assumes indicators are measured similarly over time and eliminates cyclical variability.

vi) Logarithmic transformation:$Y_i = ln(X_i)$. The inequality $r_{X_1X_2} > r_{X_3X_4}$ got reversed when the logarithmic transformation was used (Kovacevic, 2011).

3.3. Combining the indicators.

The development of an overall performance indicator requires the identification of critical areas and their aggregation (Chakrabartty & Sinha, 2022). Aggregating the indicators to a single index amounts to finding a function f from n-dimensional space (corresponding to n-indicators) to the real line. Choice of f can affect the OPPI, further operations on OPPI, and implications of OPPI. Researchers used various aggregation approaches to assess overall port efficiency.

Addition with equal importance to the indicators implies perfect substitutability among the indicators, where lower value of an indicator (say cargo throughput) can be compensated by a higher value of another indicator (say income per vessel). Park and De (2004) used a combination of physical and financial indicators without specifying any functional form.

Weighted sum approach: Here, $\text{OPPI} = \sum_{i=1}^{n} W_i X_i$ or $\overline{OPPI} = \frac{1}{n}\sum_{i=1}^{n} W_i X_i$where $0 < W_i < 1$ and$\sum_{i=1}^{n} W_i = 1$. Selected weights indicate relative importance of the indicators and also the 'trade-off' between the pairs of criteria in such an aggregation process. Changing weights can affect OPPI of the ports being evaluated and can manipulate port rankings.

De and Ghosh(2003) obtained Port Performance Index (PPI_{ij}) of the i-th port in j-th time as a weighted sum where weights were factor loadings, emerged from Principal Component Analysis (PCA). However, the rank of weights changed over time. Mandal et al. (2016) constructed P_{ij}, where the weight of the i-th indicator depends on the values of the j-th indicator for $i \neq j$. Appleby & Mulligan (2000) decided weights to the indicators based on general preferences, where $\sum_{i=1}^{6} W_i > 1$ and one indicator had negative weight. $\sum_{i=1}^{n} W_i \neq 1$ violates convex property and keeps us in the dark about the properties of the OPPI.

Empirical estimation of port efficiency by DEA differed due to factors like selection of variables, methods used, associated assumptions, and sample size (Odeck and Bråthen, 2012). Efficiency values under DEA-CCR and DEA-BCC models differed (Cullinane, Ji and Wang 2006). While increasing returns to scale were observed by González and Trujillo (2008) for Spanish ports, Cullinane et al. (2006) found decreasing return of scale for British ports and other ports. Haralambides et al. (2010); Sinha & Chowdhury (2018) used variants of DEA to judge port efficiency (overall, technical and managerial) to compare output levels and the corresponding inputs deployed across different ports. The method was used to benchmark the seaports with the efficient frontiers, assuming ports are homogenous in terms of scale of operation and similar in other features. However, the homogeneity conditions may not always be fulfilled. Different Indian ports having various drafts allow visit of vessels with different size. SFA aims to estimate the frontier (efficiency) and deviation from the frontier (showing inefficiency). However, the frontier may change with time. Cullinane et al. (2006) found high correlations between DEA and SFA.

For combining subjective criteria, Rezaei et al. (2018) proposed the Best-Worst Method (BWM) involving stages to find weights based on Tchebychev distance, requiring fewer pairwise comparisons than Analytic Hierarchy Process (AHP). However, significant limitations of BWM are lack of threshold for the consistency ratio, ordinal consistency, and complex calculation process, especially for large *n*.

Ugboma et al. (2006) used AHP to select transshipment ports by shipping liners for the Taiwanese and Nigerian seaports. Yuen et al. (2012) used AHP considering three groups of port users, viz. shipping liners, forwarders, and shippers and found differences in group perception of port competitiveness. Carlucci and Schiuma(2007) addressed limitations of AHP in realistic environment. The weight vector of AHP, as the principal eigenvector through PCA, has several drawbacks (Chunhao et al. 2008).

Tongzon and Heng (2005); Nayak et al. (2021) used PCA to identify the critical factors of port competitiveness. However, use of PCA was not favoured (ESI, 2002). Lu et al. (2016) examined port sustainability performance using Factor analysis (FA). Pantouvakis (2006) experienced problems in shipping-specific Exploratory Factor Analysis (EFA) studies. PCA and FA failed for the Economic Sentiment Indicator and environmental sustainability index (Nardo et al. 2005). Lu et al. (2016) reported the inappropriate calculation of factor scores.

Multiple Linear regression presumes linearity, which is not the norm with OPPIs. The dependent variable (Y) reflecting overall efficiency may not be observable. However, if Y is chosen as an output measure, the construction of OPPI is unnecessary. Kim and Sachish (1986) used total factor productivity (TFP) for the port of Ashdod (Israel) and found technical progress contributed more to TFP growth. TFP changes may be decomposed into technological and efficiency changes from the management perspective. However, there are different methods to decompose TFP efficiency.

Each of the above methods has advantages and disadvantages too. However, the ways of combining the selected indicators are not without problems. No weight or equal weights are wrong, and no weighting system is above criticism (Greco et al., 2019). Similarly, no ideal aggregation scheme exists (Arrow and Raynaud, 1986).

4. Proposed method.

4.1. Pre-processing of data.

i. Identify relevant KPIs from physical, financial, customer perceptions, and sustainability perspectives.

ii. Ensure each indicator is positively related to performance. For negative indicators, consider the reciprocal of values.

iii. Mark the response-categories of Likert items as 1, 2, 3, 4, 5, etc., avoiding zero.

4.2. Methodology.

Let $X_{it}>0$ denote the value of the *i*-th indicator for the *t*-th period of a port, obtained after data pre-processing mentioned above. The indicators could be independent or interrelated. Let $X_{i0}>0$ denote the indicator's value in the base period. The unit free ratio $\frac{X_{it}}{X_{i0}}$ indicates progress or decline of the port with respect to the *i*-th indicator at the *t*-th period over the base period.

OPPI of a port for the current period may be defined as the Geometric mean i.e.

$$\mathrm{OPPI}_{c0} = \sqrt[n]{\frac{X_{1c}, X_{2c}, \ldots\ldots.., X_{nc}}{X_{10}X_{20}.\ldots\ldots.\,X_{n0}}} \tag{1}$$

or by avoiding the *n*-th root,

$$OPPI_{c0} = \frac{X_{1c}, X_{2c}, \ldots\ldots.., X_{nc}}{X_{10}X_{20}.\ldots\ldots.\,X_{n0}} \tag{2}$$

$\mathrm{OPPI}_{c0}>1$ implies overall improvement from the base year. $\frac{\mathrm{OPPI}_{i_t}}{\mathrm{OPPI}_{i_{(t-1)}}}>1$ quantifies overall progress made in the current period over the previous period. The proposed OPPI may be multiplied by 100 to reflect readily percentage changes.

The indicators for which $\frac{X_{it}}{X_{i0}} < 1$ are critical. For two successive periods, critical areas of a port can be identified and ordered by observing the indicators for which $\frac{X_{it}}{X_{i(t-1)}} < 1$ and may be used for policy purposes to decide the appropriate action plan.

The proposed OPPI avoiding normalization and selection of weights is continuous, increases monotonically and satisfies the following desired properties:

1. Independent of the order of the chosen indicators and independent of change of scale

2. Reduced substitutability among the component indicators.

3. No bias for developed or under-developed ports, as outliers do not affect OPPI much.

4. OPPI of a port does not consider the performance of other ports.

5. Satisfies time-reversal test since $OPPI_{t0}.OPPI_{0t} = 1$.

6. Facilitates the formation of chain indices since $OPPI_{20} = OPPI_{21}.OPPI_{10}$. This may help draw the growth curve of OPPI registered by a port over time. Different ports can also be compared with respect to such paths. The growth curve depicting OPPI of a port gives a visual illustration of the consistency of its overall performance. Besides, the coefficient of variation (CV) of OPPI-values of a port for several years indicates the consistency of growth.

7. Possible to construct an index for each chosen domain by considering all the indicators related to that domain, and OPPI can be expressed as the product of domain indices.

8. Easy to find the relative importance of each indicator/domain.

9. Facilitates computation of OPPI of several ports in the sample and estimation of population GM considering:

$\log GM = \frac{1}{n}\sum_{i=1}^{n} \log Y_i$ where $Y_i = \frac{X_{it}}{X_{i0}}$.

Geometric standard deviation (S_{GM}), is given by:

$\log S_{GM} = [\frac{1}{n}\sum_{i=1}^{n} (\log Y_i - \log GM)^2]^{\frac{1}{2}} \Longrightarrow$

$\log (S_{GM}$ of $Y_1, Y_2, \ldots, Y_n)) = SD (\log Y_1, \log Y_2,, \ldots, \log Y_n)$

For large n, the sample GM is the estimate of population GM. Estimate of Standard error of the GM =Sample GM. $\frac{\log S_{GM}}{\sqrt{n-1}}$ Thus, statistical hypotheses regarding GM's difference can be tested using conventional *t*-tests on the observations' logarithms.

The proposed OPPI can be applied for all indicators, including those in percentages or ordinal scales. Replacing the base period vector by the vector for the previous year will indicate an improvement in OPPI on year-to-year basis. The proposed OPPI is non-parametric without assuming the distribution of the chosen indicators or the nature of measurement scales.

5. Empirical illustration.

Annual data on the following variables were collected for the Major ports of India from 2012 to 2017 from publications of the India Ports Association (IPA: Major ports - a profile, 2018) and annual reports of individual ports.

5.1. Domain Classification.

Domain I: Physical Performance:

X_1: Average Turnaround time (TAT).
X_2: Average pre-berthing detention (PBD).
X_3: Average idle time of vessels at berth.
X_4: Average Output per ship-berth-day.
X_5: Average load per vessel (Parcel Load).
X_6: Berth occupancy (BO).
X_7: Total traffic handled.

Domain II: Financial performance.

X_8: Operating income (OI).
X_9: Operating Expenditure (OE).

5.2. Correlation Analysis.

The correlation between average turnaround time (TAT) and average pre-berthing detention (PBD) was high (0,76) as PBD is a component of TAT. PBD increased with an average load per vessel (Parcel Load) as the berths remain occupied when the cargo volume increases. It is also reflected in the correlation coefficient (0,5) between PBD and Parcel Load. The average output per ship-berth-day was significantly correlated (0,625) with Parcel Load. Correlation between total traffic handled and Parcel Load was 0.658. Operating income (OI) and expenditure (OE) were highly correlated (0,884).

Table 2 shows the correlation matrix of the chosen performance indicators.

Table 2: Correlation matrix.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1	0.763**	0.493**	-0.408**	0.188	0.370**	0.263*	0.156	0.273
X_2		1	0.126	0.078	0.501**	0.396**	0.478**	-0.091	-0.13
X_3			1	-0.638**	-0.121	0.018	-0.053	0.186	0.448**
X_4				1	0.625**	0.066	0.503**	-0.118	0.433**
X_5					1	0.176	0.658**	-0.288*	-0.471**
X_6						1	0.317**	0.235	0.076
X_7							1	0.302*	0.077
X_8								1	0.884**

**: Correlation is significant at 1% level;
* Correlation is significant at 5% level

Source: Authors.

5.3. Step-wise regression analyses.

Separate Step-wise regression analyses were undertaken by choosing dependent variables such as TAT(from the stakeholders' perspective), Total traffic (from the ports' viewpoint), Operating income and Operating surplus (from both shareholders' and ports' perspectives).Table 3 shows the regression results and the variables to predict the dependent variable.

Table 3: Stepwise regressions.

Dependent variable	**Independent variables (in order of beta coefficient for predicting the dependent variable)**	**Step-wise Regression Equation**	R^2
Average TAT (X_1)	PBD(X_2); Output (X_4); Parcel (X_5);OE (X_9)	$X_1 = 2.287 + 0.686X_2 - 0.535 X_4 + 0.309 X_5 + 0.277X_9$	0.876
Total Traffic (X_7)	Parcel (X_5); OI(X_8); PBD (X_2); TAT (X_1)	$X_7 = - 20990.467 + 0.683X_5 + 0.568X_8 + 0.366X_2 - 0.234X_1$	0.857
Operating Income (X_8)	OE (X_9); Output (X_4); BO (X_6); Idle time (X_3)	$X_8 = -4876.084 + 1.032X_9 + 0.237X_4 + 0.144X_6 - 0.127X_3$	0.946
Operating Surplus (X_{10})	OI (X_8); OE (X_9); Output (X_4); Idle time (X_3); BO (X_6)	$X_{10} = - 4205.086 + 1.135X_8 + 0.997 X_9 + 0.287 X_4 - 0.215X_3 + 0.208X_6$	0.944

Source: Authors.

The Table reveals:

- TAT was affected most by PBD, output (negatively correlated) and parcel load. Output impacts TAT in the opposite direction and are associated with total traffic as a dependent variable. Beta-coefficient values in an equation indicate the relative importance of the independent variables for predicting the dependent variable.

- Total traffic increased with Parcel (X_5) but decreased with an increase in TAT(X_1). An increase in X_5 increased OI. The positive beta of PBD for predicting X_7 indicates that the rise in ship calls results in higher PBD and a higher level of traffic handled by the port.

- Relationship of OI with significant independent variables is OE (X_9); Output(X_4); BO(X_6); Idle time(X_3). Each independent variable except idle time (X_3) affected income positively. The positive relationship with OE (X_9) hints at an increase in expenditure associated with an increase in operating income. The association between Output (X_4) and BO (X_6) suggests that though the former reduces BO(X_6) per vessel, the overall BO (X_6) increases with an increase in the number of vessel calls.

- Operating Surplus (X_{10}) was most correlated with OI.

5.4. *Computation of OPPI.*

Considering 2012 as the base period, OPPI for each major port was computed considering the reciprocal of negative variables in physical and financial domains using (2).

$$\mathrm{OPPI}_{t0}=\mathrm{PhysicalPPI}_{t0}\times\mathrm{FinancialPPI}_{t0} =$$

$$\prod_{i=1}^{7}\frac{\text{Values of } X_i \text{in t} - \text{th year}}{\text{Values of } X_i \text{in 2012}}\times\prod_{i=8}^{9}\frac{\text{Values of } X_i \text{in t} - \text{th year}}{\text{Values of } X_i \text{in 2012}}$$

Details of the computation of port-wise OPPI are shown in Table 4.

Table 4: Port-wise OPPI across years.

Port		2013	2014	2015	2016	2017
Kolkata	$\mathrm{PhysicalPPI}_{t0}$	1.493520	2.454019	3.933938	2.478282	2.944480
	$\mathrm{FinancialPPI}_{t0}$	1.144845	1.204767	1.255780	1.310915	1.424569
	OPPI_{t0}	1.709850	2.956521	4.940161	3.248818	4.194614
Paradip	$\mathrm{PhysicalPPI}_{t0}$	1.211492	0.234896	0.975624	1.728436	4.972577
	$\mathrm{FinancialPPI}_{t0}$	1.073537	1.096757	1.148027	1.212929	1.318616
	OPPI_{t0}	1.300581	0.257624	1.120043	2.096470	6.556920
Visakhapatnam	$\mathrm{PhysicalPPI}_{t0}$	1.497874	0.774412	2.388455	4.492317	72.147047
	$\mathrm{FinancialPPI}_{t0}$	0.965502	1.141876	1.145445	1.201785	1.336219
	OPPI_{t0}	1.446201	0.884282	2.735844	5.398799	96.404277
Chennai	$\mathrm{PhysicalPPI}_{t0}$	3.028785	3.489375	2.478086	3.006111	18.597986
	$\mathrm{FinancialPPI}_{t0}$	0.939752	1.150677	1.255195	1.292002	1.330241
	OPPI_{t0}	2.846307	4.015142	3.110481	3.883903	24.739808
VOC Port	$\mathrm{PhysicalPPI}_{t0}$	1.833037	2.742953	2.392679	1.587380	2.535216
	$\mathrm{FinancialPPI}_{t0}$	0.944604	1.181532	1.333411	1.398153	1.465750
	OPPI_{t0}	1.731494	3.240886	3.190424	2.219401	3.715991
Cochin	$\mathrm{PhysicalPPI}_{t0}$	0.439913	0.692961	1.035581	1.830127	3.598972
	$\mathrm{FinancialPPI}_{t0}$	1.116635	1.241935	1.407180	1.587631	1.691371
	OPPI_{t0}	0.491223	0.860613	1.457249	2.905567	6.087199
NMPT	$\mathrm{PhysicalPPI}_{t0}$	0.436670	1.757078	1.013615	1.770204	1.300308
	$\mathrm{FinancialPPI}_{t0}$	0.912624	0.932577	0.866923	0.946921	1.021457
	OPPI_{t0}	0.398516	1.638611	0.878726	1.676245	1.328209
MGPT	$\mathrm{PhysicalPPI}_{t0}$	0.285497	0.368225	1.407081	1.508534	2.827733
	$\mathrm{FinancialPPI}_{t0}$	1.026978	1.359465	1.677885	1.937997	1.819910
	OPPI_{t0}	0.293199	0.500590	2.360920	2.923535	5.146219
JNPT	$\mathrm{PhysicalPPI}_{t0}$	1.107817	1.616031	0.963277	1.820843	2.524164
	$\mathrm{FinancialPPI}_{t0}$	1.220691	1.245157	1.331939	1.171573	1.395525
	OPPI_{t0}	1.352303	2.012214	1.283025	2.133251	3.522535
Mumbai	$\mathrm{PhysicalPPI}_{t0}$	0.793446	0.450307	0.811718	2.647728	1.286330
	$\mathrm{FinancialPPI}_{t0}$	1.098545	1.233919	1.293835	1.251638	1.228933
	OPPI_{t0}	0.871636	0.555642	1.050230	3.313997	1.580814
Deen Dayal	$\mathrm{PhysicalPPI}_{t0}$	2.006178	1.624077	2.580266	16.738775	7.882190
	$\mathrm{FinancialPPI}_{t0}$	0.818058	0.940688	1.042643	1.385420	1.447757
	OPPI_{t0}	1.641171	1.527749	2.690295	23.190229	11.411495
All Major Ports taken together	$\mathrm{PhysicalPPI}_{t0}$	1.034692	1.077112	1.588023	2.596836	4.539482
	$\mathrm{FinancialPPI}_{t0}$	1.017431	1.150352	1.234682	1.315583	1.392615
	OPPI_{t0}	1.052728	1.239059	1.960704	3.416354	6.321749

Source: Authors.

5.5. *Contribution in OPPI.*

$\frac{\mathrm{PhysicalPPI}_{t0}}{\mathrm{OPPI}_{t0}}\times 100$ for Physical efficiency and $\frac{\mathrm{FinancialPPI}_{t0}}{\mathrm{OPPI}_{t0}}\times 100$ for financial efficiency):

All Major Ports	$\mathrm{PhysicalPPI}_{t0}$	98.29%	86.93%	80.99%	76.01%	71.81%
	$\mathrm{FinancialPPI}_{t0}$	96.65%	92.84%	62.97%	38.51%	22.03%

5.6. *Observations.*

OPPI improved for each port from 2102 to 2017, the highest at Visakhapatnam Port (96.40%), followed by Chennai (24.74%). For all the Major Ports taken together, OPPI improved by 6.32% in 2017 with respect to 2012.

Performance in the Physical domain improved for all the Ports in 2017 except Mumbai Port and NMPT. Major Ports were influenced by the Physical domain to OPPI as $\frac{\mathrm{PhysicalPPI}_{t0}}{\mathrm{OPPI}_{t0}}\times 100$ was higher than the same for the financial domain for each year barring 2014.

Ranks of Ports in terms of OPPI and component domains are given in Table 5.

Table 5: Rank of ports in terms of $OPPI_{2017,\{2012}$ and their component domains.

Ports	Ranks in terms of			Remarks	
	$\mathrm{OPPI}_{17,12}$	Phy $\mathrm{PPI.}_{17,12}$	Fin. $\mathrm{PPI}_{17,12}$	Physical PPI	Financial PPI
Visakhapatnam	I	I	VII	Highest growth	Steady growth till 2015, declined in 2016 & improved in 2017
Chennai	II	II	VIII	Declined in 2015	Steady increase from 2012
DeenDayal	III	III	IV	Declined from 2016.	Steady increase from 2012
Paradip	IV	IV	IX	Steady increase from 2015	Steady increase from 2012
Cochin	V	V	II	Increased steadily from 2012	Steady increase from 2012
MGPT	VI	VII	I	Increased steadily from 2012	Growth reduced from 1.94 in 2016
Kolkata	VII	VI	V	Increased steadily up to 2015. Declined in 2016 and improved in 2017	Steady increase from 2012
VOC Port	VIII	VIII	III	Declining trend in 2015, 2016 arrested and improved in 2017	Steady increase from 2012
JNPT	IX	IX	VI	Increased steadily from 2015	Continued growth up to 2015 declined in 2016. Improved in 2017
Mumbai	X	XI	X	Declined in 2017 over 2016	Growth reduced from 1.29 in 2015
NMPT	XI	X	XI	Declined in 2017 over 2016. Still lower than the 2014 level of growth	The minimum was for 2015. After that registered an improving trend

Source: Authors.

5.7. *Coefficient of Variance Analysis.*

Analysis of the coefficient of variation (CV) of OPPI values aids in understanding the consistency in the ports' growth. Empirically, a higher CV value was associated with fewer turning points in the OPPI curve. Table 6 shows the CV of OPPI-values of different ports during 2013-2017. Port-wise growth of OPPI graphs and component domains along with CV are shown in Figures 1 to 11.

Table 6: CV of OPPI (2013 ? 2017)

Major Port	CV of OPPI	Ranks in terms of CV	No. of turning points in OPPI Curve (2013–2017)
Kolkata	0.323357	X	4
Paradip	0.981099	IV	3
Visakhapatnam	1.756700	I	1
Chennai	1.104001	II	2
VOC Port	0.258812	XI	4
Cochin	0.862964	V	3
NMPT	0.410273	VIII	4
MGPT	0.790440	VI	4
JNPT	0.391316	IX	4
Mumbai	0.663318	VII	4
Deen Dayal	1.038121	III	3

Source: Authors.

OPPI Curves of different major ports of India are shown in Figures 1 to 11 (See next page).

Visakhapatnam Port registered the most consistent growth in OPPI, followed by Chennai. The Zigzag pattern of OPPI growth curves had a low value of CV.

Critical areas of a port requiring attention are the indicators for which $\frac{X_{i\ 2017}}{X_{i1992}}$<1. In addition, corrective measures may be initiated for the indicators where a port registered a decline compared to the previous year, i.e. the indicators for which $\frac{X_{i,2017}}{X_{i,2016}}$<1 . Table 7 indicates port-wise critical areas.

Table 7: Port-wise critical areas.

Ports	Critical areas in terms of		Actions required by ports
	$\frac{X_{i\ 2017}}{X_{i2012}} < 1$	$\frac{X_{i,2017}}{X_{i,2016}} < 1$	
Kolkata	PBD BO Expenditure	PBD Output Expenditure	The port should aim to reduce PBD and expenditure, preferably through its process reengineering – optimizing its resource uses and enhancement of output.
Paradip	Expenditure Idle Time	Expenditure Idle time BO	Idle time needs to be reduced, preferably through collaboration between stakeholders- stevedores, shipping agents and port divisions – traffic, marine and mechanical engineering for equipment supply. This will lead to favourable berth occupancy as well. Outsourcing, process reengineering and optimization may be explored to minimize expenditure.
Visakhapatnam	Expenditure	Expenditure Idle time BO	Same as recommended for Paradip port.
Chennai	-	Income	This port needs to relook at the sources (vessel calls, berth hire, and cargo handling) where income dropped and take remedial actions accordingly.
VOC Port	TAT Idle Time	Total traffic	The increase in TAT and idle time is likely to affect annual traffic, and it seems it affected the port in 2017.
Cochin	-	BO	An increase in productivity can bring down the BO. However, if annual cargo drops, the BO decreases, and as such, it requires attention.
NMPT	PBD Expenditure	PBD Output Expenditure	The port may implement virtual arrival (VA) system for charter vessels and enhance output for container liners to minimize PBD. A spend analysis may indicate the areas of high or sub-optimal expenditure.
MGPT	PBD Income Expenditure	Total traffic BO Expenditure Income	Physically and financially, the port needs improvement; a re-structuring of its institutional mechanism and operations needs to be done.
JNPT	BO Output	TAT Output	The Drop in output has led to increased TAT, and the port needs to conduct process reengineering and value analysis to improve.
Mumbai	Expenditure Idle Time	Total traffic TAT PBD BO	An increase in idle time has led to an increase in TAT and PBD and a decrease in annual traffic. Minimization of idle time through collaboration and optimization of resources may be explored.
Deen Dayal	Expenditure	Idle Time Parcel Load Expenditure	A spend analysis may indicate the areas of high or sub-optimal expenditure.

Source: Authors.

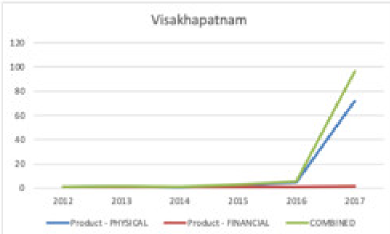
Conclusions.

Measures based on a single indicator are inadequate for effectively comparing ports. An overall - port - performance - indicator (OPPI) is proposed considering multi-criteria goals, system boundaries, subsystems, and components for meaningful comparisons of ports across time and space. Disadvantages of the existing methods of measuring overall port performance involving a set of assumptions and complex calculations may be avoided by the proposed method, which offers a simple solution without scaling or finding weights or reducing the component indicators' dimensionality. The proposed index, in terms of Geometric Mean (GM), is non-parametric and reflects overall improvement/decline by a port in the current year with respect to the base year without considering the performance of other ports. Thus, the proposed index considers the uniqueness of ports.

The proposed index satisfies the desired properties. It includes unit-free monotonically increasing continuous function, linearity between the gain in an indicator and gain in OPPI, time-reversal test, formation of chain indices, identification of the critical areas, and can be applied even for skewed data and also for more dimensions. The measure can also be used to find the growth curve of the OPPI of each port. This, in turn, provides another criterion for comparison among ports. The coefficient of variation (CV) of OPPI-values of a port for several years indicates the consistency of growth. A port registering a significant increase in OPPI had a high CV value. The higher the number of turning points (points of inflection), the lower the CV value.

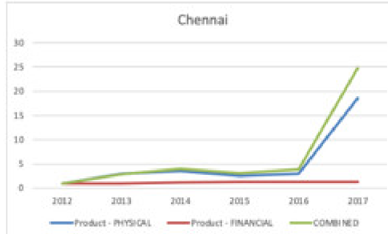
Empirically, the overall efficiency of major ports of India was analysed using the proposed OPPI and its two domains, viz. physical efficiency and financial efficiency, for each year (between 2013 to 2017) with 2012 as the base year. The contribution of Physical domain efficiency to OPPI was higher than the Financial domain efficiency. Improvement in the Financial domain was slow for the Ports. Statistical properties of GM facilitated the estimation of year-wise OPPI of the group of ports. Results show that in 2017, OPPI for all Major Ports taken together improved by 6.32%. Visakhapatnam registered the maximum growth of OPPI with a maximum value of CV (showing consistency), followed by Chennai and Deen Dayal, in that order. OPPI in 2017 improved for each port except Mumbai and NMPT compared to 2016. The results showed port-wise critical areas requiring attention and indicated remedial actions.

The proposed method with wide application areas satisfying desired properties is an improvement over the existing methods. Future studies may be undertaken to prescribe effective and implementable standards for improving OPPI and benchmarking Indian Ports and indicate the impact of the suggested measures when implemented.



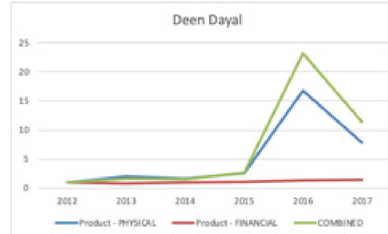
CV = 1.76

Figure 1: OPPI curve of Visakhapatnam Port



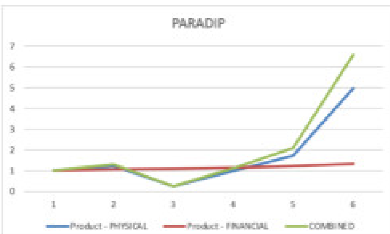
CV = 1.10

Figure 2: Growth curve of Chennai Port



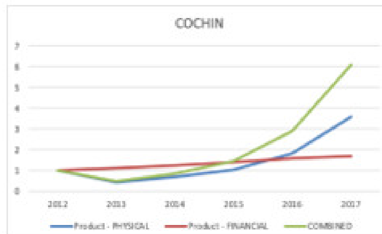
CV = 1.04

Figure 3: Growth curve of Deen Dayal Port



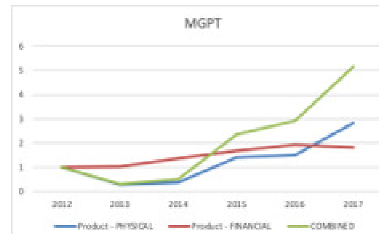
CV =0.98

Figure 4: Growth curve of Paradip Port



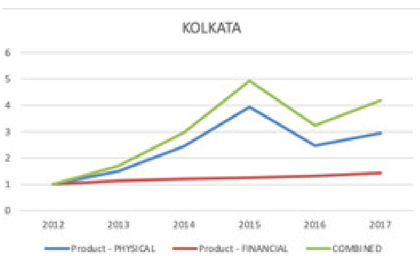
CV =0.86

Figure 5: Growth curve of Cochin Port



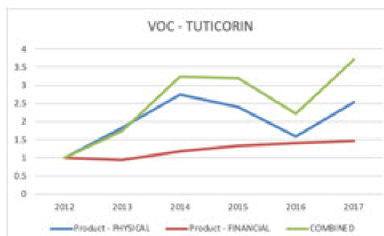
CV =0.79

Figure 6: Growth curve of MGPT Port



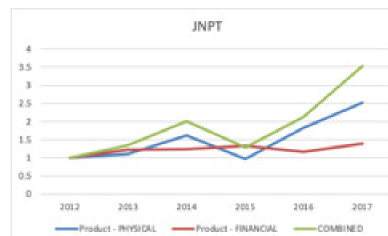
CV =0.32

Figure 7: Growth curve of Kolkata Port



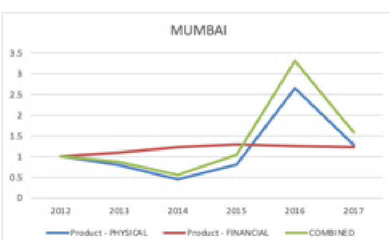
CV = 0.26

Figure 8: Growth curve of VOC Port



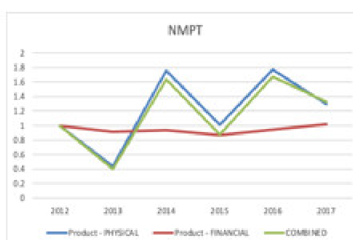
CV = 0.39

Figure 9: Growth curve of JNPT Port



CV = 0.66

Figure 10: Growth curve of Mumbai Port



CV = 0.41

Figure 11: Growth curve of NMPT Port

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