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EFFICIENCY APPRAISAL OF INDIAN MAJOR PORTS USING DATA ENVELOPMENT ANALYSIS APPROACH

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Abstract:

The seaport infrastructure has gained tremendous importance with the rising volume of international trade in the era of globalization. As the majority of international merchandise trade is handled by seaports, an efficient seaport infrastructure provides comparative advantages to the nation in global market. The efficiency of seaports considerably relies on their capacity to utilize the available resources in an optimal manner. Therefore, the systematic appraisal of seaport efficiency can reveal their relative positions in the competitive environment. Since 1990's, India emphasized on international trade oriented growth, necessitating efficient port infrastructure. As majority of India's international trade in volume is handled by seaports, the efficiency of seaport sector becomes the prime matter of concern for policy makers. This paper applies Data Envelopment Analysis (DEA) for efficiency appraisal of Indian Major Ports. As a feedback to the port operations in India, this paper supplements existing studies by deriving relative efficiency estimates of 12 major ports of India and identifying sources of inefficiency at relatively inefficient 5 major ports of India.

Subject: *Economics*

Key Words: *Indian Port, Efficiency, Sources of Inefficiency, Data Envelopment Analysis (DEA)*

1. INTRODUCTION

With the increasing world trade due to globalization, the seaports have gained tremendous significance as majority of global merchandise trade is handled by seaports. The seaports are nodal points that link the open economy with the global world. Consequently, the seaport infrastructure becomes the prime issue of concern for policy making in an economy. An efficient seaport infrastructure provides comparative advantages to the nation in global market. The efficiency of seaports considerably relies on their capacity to optimally utilize the available resources. The systematic appraisal of seaport efficiency can reveal their relative positions in the competitive environment. The seaport efficiency appraisal provides a feedback to port authorities for designing appropriate strategies to achieve and maintain a competitive edge in the international market.

Since 1990's, India emphasized on international trade oriented growth, necessitating efficient port infrastructure. Over the last decade, there has been a steady increase in handling of cargo traffic at Indian ports. To sustain the momentum of handling cargo the adequate and efficient port infrastructure becomes the necessary precondition to improve competitiveness. Therefore, the port performance becomes the thirst area of analysis to review the dynamics of port developments in India. By appraisal of efficiency of Indian Major Ports, the sources of inefficiency can be identified. In this context, the present paper applies Data Envelopment Analysis (DEA) for efficiency appraisal of Indian Major Ports. The DEA technique provides relative efficiency estimates for Indian Major Ports and also identifies sources of inefficiency at relatively inefficient Indian Major Ports.

This paper has twin objective: firstly to identify the efficient and inefficient major ports of India on the basis of the acquired efficiency scores using DEA and secondly to identify the sources of inefficiency at inefficient ports. The paper is organized as follows. Section I deals with the brief introduction, while Section II reviews the literature on maritime sector and methodology used. The conceptual framework of efficiency measurement and DEA methodology to measure the efficiency is presented in Methodology Section III. The Section IV pertaining to Data and Analysis deals with Indian port sector and application of the DEA to Indian major ports for efficiency measurement and identifies the sources of inefficiency. The last section deals with the summary of the paper and discussion about the further research.

2. LITERATURE REVIEW

Various studies have been initiated on maritime sector since 1970's. The first generation of studies on ports analyzed ports' production and cost structure to manage future investments. Port costs and port demand was examined by Peston and Rees (1971), while Wanhill (1974) designed a model to determine the optimal number of berth minimizing the total port cost. Goss (1976) studied port pricing, port capacity and port investment, whereas, the port pricing and investment policies were formulated by Bennathan and Walters (1979) for developing economies. The analysis of investment in Nigerian ports was undertaken by Shneerson (1981), while De Monie (1987) proposed tools to measure port performance and productivity. Reker *et al* (1990) developed the production function for Melbourne container terminal, whereas Talley (1994) evaluated port performance using selected port performance indicators. Ghosh and De (2000) investigated the impact of performance indicator and labour endowment on Indian port traffic.

Haralambides (2002) studied port competition, excess capacity and the pricing of port infrastructure. Notteboom and Rodrigue (2005) advocated port regionalization model for port sector development. De (2006) assessed the total factor productivity growth of the Indian port sector using Cobb-Douglas production function. Roh *et al* (2007) designed a port logistics process model using the structured analysis. Mangan and Lalwani (2008) proposed port centric logistics for competitive gains, while Chudasama (2009a) analysed the performance of Indian major ports using Weighted Score Method by deriving weights from factor loadings of the Principal Component Analysis. Verhoeven (2010) reviewed port authority functions with an approach of renaissance, while Chudasama (2010) reviewed Port-based Development in Gujarat state of India, whereas, He and Ji (2011) proposed Green Port Construction of Tianjin Port of China. Chudasama *et al* (2012) conducted Socio-Economic Impact Assessment (SEIA) of port based development in Gujarat State of India using Coherently Augmented Socio-Economic Status Scale, while Rosa *et al* (2013) proposed Analytic Hierarchy Process (AHP) model to identify key factors of seaport competitiveness based on the stakeholder perspective, whereas, Cheng H. *et al* (2014) assessed port vulnerability from the critical infrastructure interdependency perspective and Dwarakish and Salim (2015), reviewed the role of ports in the development of a nation.

Simultaneously, the comparative studies and analysis of port efficiency using Data Envelopment Analysis (DEA) gained importance in 1990’s. Roll and Hayuth (1993) analyzed efficiency of 20 container ports with 3 inputs and 4 outputs using DEA. Poitras *et al*. (1996) applied DEA to provide an efficiency ranking for 5 Australian and 18 other international container ports. Martinez *et al*. (1999) applied DEA to evaluate the efficiency of 26 container ports in Spain with 3 inputs and 1 output. Using DEA additive model with 6 inputs and 2 outputs, Tongzon (2001) examined the efficiency of 4 Australian and 12 other international container ports. The efficiency of 11 Korean container ports with 2 inputs and 4 outputs was examined by Park and De (2004) using 4-Stage DEA. Cullinane *et al.* (2004) applied DEA Windows Analysis to 25 container ports for evaluating production efficiency. The efficiency of 53 international container ports was evaluated using DEA by Song and Sin (2005). Hsuan *et al.* (2005) applied Recursive Data Envelopment Analysis (RDEA) to derive relative efficiencies and rank selected container ports in Asia Pacific region. The cross section DEA was applied by Cullinane and Wang (2006) to 69 European container terminals to measure the relative efficiencies. Soon *et al.* (2007) ranked 19 major container terminals in Northeast Asia using super efficiency DEA. Chudasama and Pandya (2008) evaluated efficiency of Indian major ports and examined the possibility of increase in output at inefficient ports, while Chudasama (2009b) analysed efficiency of Major Ports of India using DEA and identified scope of improvement. Wu and Goh (2010) compared the container port efficiency of ports in emerging markets (BRIC) with the more advanced markets (G7); while Lan *et al.* (2011) analysed dynamic efficiency of main ports in mainland China, Hongkong and Taiwan based on DEA-Malmquist Productivity Index; whereas, Pjevcevic *et al.* (2012) measured port efficiencies in Serbia using DEA window approach. Bichou (2013) studied the impacts of operating and market conditions on container port efficiency; while, Rajasekar *et al.* (2014) measured efficiency of major ports in Indi using DEA analysis approach International Port System. Van Dyck (2015) assessed the port efficiency in West Africa using DEA approach. Following the seminal research on port sector worldwide, the present paper appraise the efficiency of Indian major ports and identifies the efficient ports, inefficient ports and the sources of inefficiency at ports using DEA.

3. METHODOLOGY

3.1. Efficiency Measurement

Efficiency is the success with which an organisation uses its resources to produce outputs. It is the degree to which the observed use of resources to produce outputs of a given quantity matches the optimal use of resources to produce outputs of a given quantity. The technical definition of efficiency was given by Koopmans (1951), while Farrel (1957) proposed the comprehensive idea of *Technical Efficiency* which is termed as the proportional reduction in inputs possible for a given level of output in order to obtain the efficient input use (the firm’s ability to obtain maximum output, given the set of input combination). Considering the Input-Oriented approach, the technical efficiency is about maximum possible reduction in inputs when the output is given, while considering the Output-Oriented approach, the technical efficiency is about maximum possible increase in outputs when the input is given.

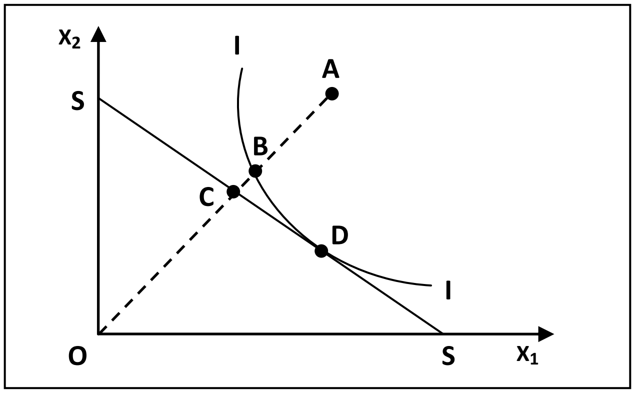
On the other hand *Allocative Efficiency* or *Price Efficiency* which reflects the ability of the firm to use the inputs in optimal proportions, given their respective prices (the firm's ability to use the given set of input combination in optimal proportion at their respective prices) and the product of Technical Efficiency and Allocative Efficiency / Price Efficiency was popularized as *Economic Efficiency* or *Overall Efficiency*.

The Technical Efficiency and Allocative Efficiency can be understood from the Figure1. The Isoquant curve II represents the unit Isoquant of an efficient producer. Let A be a point which represents the combination of two inputs X_1 and X_2 per unit of output. If a line is drawn from the origin to point A, it will cut the efficient Isoquant at point B. It means that if the inputs can be reduced equiproportionately, the efficient point will be at B, which must lie on the efficient Isoquant II.

Thus, point B represents the combination of inputs in the same proportion as in point A, but with a lesser amount of both inputs to produce a unit level of output. OB/OA fraction of inputs is now needed to produce the same level of output or in other words, OA/OB times of output can be produced from the same level of the input. The ratio OB/OA can be interpreted as Technical Efficiency (TE) of any production unit. Thus, if the production unit is technically efficient, the values will be 1 (OB=OA) and any value below 1 indicates a technically inefficient unit.

Figure 1:

Technical Efficiency and Allocative Efficiency



Source: Ranjan Ghosh & Chiranjib Neogi (2005)

In the above definition of efficiency, the role of input price in measuring efficiency is not considered. Now if one has to assess the efficient allocation of inputs in terms of input price, then the price line or Isocost line SS in the Figure 1 should be introduced to measure efficiency. The point C on the line SS represents the minimum cost required, given the price of inputs for the use of same proportion of inputs as is used at point B. Thus, OC/OB gives the measure of Price Efficiency or Allocative Efficiency (AE). Now, if the firm can the change the proportion of inputs to the point D, then the firm can attain both the minimum cost of input as well as optimum efficiency from the input used. However, it may not always be possible to change the proportion of inputs keeping the same level of Technical Efficiency. If the production unit is perfectly efficient, both technically and in respect of price, the ratio OC/OA will be the measure of Overall Efficiency or Economic Efficiency (EE).

The product of Technical Efficiency and Allocative Efficiency represents the overall Economic Efficiency (EE). Therefore EE = TE × AE = (OB/OA) × (OC/OB) or EE = OC/OA

All the three efficiencies are measured along the line from origin to the observed point of production and so, it holds the relative proportion of inputs or output constant. Since the derived efficiency measures are units invariant, the value of efficiency measures will not change even if the measurement units are changed.

3.2. Data Envelopment Analysis (DEA)

DEA is a linear programming based non-parametric method to measure the relative efficiency of the decision making units (DMUs) that use similar multiple input(s) to produce similar multiple output(s). Charnes, Cooper and Rhodes (1978) extended the Farrell's (1957) work of measuring technical efficiency and introduced the data envelopment analysis, later on called as the DEA-CCR model, which investigated efficiency assuming constant returns to scales. Banker, Charnes and Cooper (1984) extended the CCR model which was called the DEA-BCC model that investigated efficiency assuming variable returns to scales. The DEA asserts that efficiency of any DMU is verified by its ability to convert inputs into outputs.

According to this approach, the efficiency is always less than or equal to one due to some energy loss that occurs during the transformation process. The nonparametric computation in DEA, the prior knowledge of weights for the inputs and outputs is not required. In DEA, a single 'virtual' output and single 'virtual' input is obtained without estimating the production function. The ratio of sum of weighted outputs to the sum of weighted inputs is used to measure the efficiency.

As the DEA technique is flexible, convenient and can handle multiple inputs and multiple outputs to determine the efficiency estimates, it is widely applied to measure the public services efficiency (Lewin *et al.,* 1982); post offices efficiency (Deprins et al., 1984); railway efficiency (Oum and Chunyan, 1994); efficiency of hospitals (Banker *et al*., 1986; Sarkis and Talluri, 2002); efficiency of schools (Ray, 1991) and state transport efficiency (Anjaneyulu, 2006). DEA has also been applied to evaluating the efficiencies of private airlines firms (Distexhe and Perelman, 1994; Good *et al*, 1995); efficiency of banks (Bhatacharya *et al*, 1997; Isik and Hassan, 2002; Sufian, 2007); hotel sector (Sigala, 2004); tourism (Wober, 2007); textile and apparel industry (Saricam and Erdumlu, 2012); power companies (Yang, 2013); Gas Stations (Asayesh and Raad, 2016).

By providing the observed efficiencies of individual firms, DEA may help identify possible benchmarks towards which the performance can be targeted. The weighted combinations of peers and the peers themselves may provide benchmarks for relatively less efficient firms. The actual levels of input use or output of efficient firms can serve as the specific targets for less efficient firms, while the processes of benchmarking firms can be used for the information of managers of firms aiming to improve the performance.

3.2.1. The Basic DEA Model

Suppose there are '*n*' number of DMUs, each consumes varying amount of '*m*' different inputs to produce '*s*' different outputs. Specifically, DMU_j ($j=1,\dots,n$), consumes $X_j=\{x_{ij}\}$ amount of inputs ($i=1,\dots,m$) and produces $Y_j=\{y_{rj}\}$ amount of outputs ($r=1,\dots,s$). The $m \times n$ matrix of input measures is denoted by X and $s \times n$ matrix of output measures is denoted by Y as represented below.

X is an (m × n) Input Matrix

$$X = \begin{pmatrix} x_{11} & x_{12} & x_{13} & \cdot & x_{1j} & \cdot & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdot & x_{2j} & \cdot & x_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{i1} & x_{i2} & x_{i3} & \cdot & \mathbf{x_{ij}} & \cdot & x_{in} \end{pmatrix}$$

Y is an (s × n) Output Matrix

$$Y = \begin{pmatrix} y_{11} & y_{12} & y_{13} & \cdot & y_{1j} & \cdot & y_{1n} \\ y_{21} & y_{22} & y_{23} & \cdot & y_{2j} & \cdot & y_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ y_{r1} & y_{r2} & y_{r3} & \cdot & \mathbf{y_{rj}} & \cdot & y_{rn} \end{pmatrix}$$

Moreover, assume that amount of inputs x_{ij} are always positive (i.e. $x_{ij} > 0$) and outputs y_{rj} are always positive (i.e. $y_{rj} > 0$). Focusing on any one DMU, the relative efficiency can be calculated by formulating the ratio of weighted sum of outputs to a weighted sum of inputs, subject to the constraint that no DMU can have a relative efficiency score greater than one. The efficiency of each DMU is measured once and therefore, "*n*" optimizations are needed. To calculate the relative efficiency of the DMU_j, the linear program based on the input oriented DEA-CCR can be as follows:

$$\text{Max } h_j(u,v) = \frac{\sum_{r=1}^{r=s} u_r \, y_{rj}}{\sum_{i=1}^{i=m} v_i \, x_{ij}} \qquad \text{---------------} \; (1)$$

$$\text{Subject to} \quad \frac{\sum_{r=1}^{r=s} u_r \, y_{rj}}{\sum_{i=1}^{i=m} v_i \, x_{ij}} \leq 1 \qquad \text{---------} \; (2)$$

$$u_r \geq 0 \quad \text{for } r = 1,\ldots,s$$

$$v_i \geq 0 \quad \text{for } i = 1,\ldots,m$$

If the DMU obtains an efficiency score of less than one, the unit is termed as relatively inefficient with respect to the other units in analysis and no other combination of weights can possibly make it efficient. If the unit obtains a score of one, the unit is relatively efficient (scope of improvement may still well exist), but the combination of weights makes it efficient. Like wise for each DMU, the ratio should be formulated. This means that each unit is allowed freedom in assigning the set of weights to its factor inputs, which will render the unit as efficient as possible within the constrained limit.

4. EFFICIENCY ANALYSIS OF INDIAN PORT SECTOR

4.1. Indian Port Sector

India on its 7517 kms of coastline, possesses 12 major ports governed by the Ministry of Surface Transport (MoST) Government of India and about 205 notified non major ports under the administrative controlled of State Governments in which they are located. Indian ports hold strategic position on the crucial East-West trade route, which links Europe and Far East. On the west coast of India there are six major ports: Kandla Port in Gujarat, Jawaharlal Nehru Port and Mumbai Port in Maharashtra, Murmugao Port in Goa, New Mangalore Port in Karnataka and Cochin Port in Kerala. On the east coast there are six major ports: Kamarajar Port (formerly Ennore Port), Chidambaranar Port (formerly Toticorin Port) and Chennai Port in Tamilnadu, Vishakhapatnam Port in Andhra Pradesh, Paradip Port in Orissa and twin ports Kolkata Port and Haldia Dock System in West Bengal.

In 2014-15, all the (major + non-major) ports together handled about 1052.23 Million Tons of cargo traffic, out of which 55.25% of cargo traffic was handled by major ports and remaining 44.75% of cargo traffic was handled by non-major ports.

The cargo traffic at Indian ports has grown at 8.08 % CAGR since 2000-01. During this period, the annual growth of cargo handled at non-major ports has been 30.2%, which is about 4 times the growth in cargo handled at major ports that has been 7.9%.

The operational performance of Indian major ports measured by yearly operational performance indicators like Average Turn Round Time (TRT), Average Pre-Berth Detention (PBD) and Average Output per Ship Berth Day (OSD) etc.

The average TRT refers to the average of total time spent by a vessel since its entry till its departure, while average PBD refers to the average of total time for which a vessel waits before getting entry into the berth and OSD refers to the average of total tonnage handled distributed over the total number of vessels berth days.

Therefore, lower the TRT and the PBD, the higher will be the OSD, which reveals is the operational efficiency of the port. The TRT at Indian ports ranges between 1.69 days and 7.01 days (Average TET: 3.89 days); the PBD at varies from 0.41 days to 4.11 days (Average PBD: 1.61 days) and the OSD hoovers between 3084 tonnes and 22613 tonnes (Average OSD: 12993 tonnes). Moreover, the cargo handling port capacity utilisation varies from 33.62% to 138.47% (Average capacity utilisation: 66.70%) during the year 2015.

Hence, the question arises that "how effectively Indian major ports, which handle majority of nation's seaborne trade are helping India's globalization programme?" therefore, the paper attempts to measure the efficiency of Indian major ports using Input Oriented DEA model to assess the extent of optimal allocation of input resources and also identifies the sources of inefficiency at Indian major ports.

4.2. Efficiency Analysis

4.2.1. The Input and Output Variables

As the output of a port depends on the use of available input resources, the main objective of port is assumed to be the maximization of the output, given the inputs. The volume of cargo traffic handled (in million tonnes) at port has been considered as a measure of port output. The various input resources like: Number of Vessels Handled (including Bulk / General / Container Cargo, Crude / Gas Tankers, etc.);

Number of Berths (including Barge Jetty, Single Buoy Mooring, Single Point Mooring, Transhipper, etc. handling POL, Iron Ore, Coal, Fertilizer, Container, Break Bulk Cargo); Man-Days Employed (including Port Employees as well as Dock Employees); Number of Cranes (including Mobile, Wharf, Container Yard and Quay Cranes); Number of Other Equipment (including Fork/Top lift Truck, Reach Stacker, Tractors, Trailers, Shovel Dozer, Pay Loader, Excavator, Locomotives, etc.); and the Cargo Handling Port Capacity (in Million Tonnes) has been considered as inputs, which influence the volume of port output.

The data pertaining to input and output variables of major ports of India for the year 2015 are sourced from the Ministry of Shipping (MoS), Government of India for analysis. As per the requirement of DEA Model, the numbers of DMUs (ports) has to be more than (at least twice) the sum of inputs and outputs and therefore, one output variable and six input variables have been included in the analysis. Table 1 exhibits the output and input variables incorporated in the analysis.

Table 1:

Output and Input Variables of Selected Major Ports of India (2015)

Ports	Output	Inputs					
	Y	X1	X2	X3	X4	X5	X6
Kolkata	15.28	1314	33	1515	12	81	21.10
Haldia	31.01	1907	19	896	3	36	49.75
Paradip	71.00	1400	19	646	7	7	119.80
Vishakhapatnam	58.00	1942	25	1678	20	24	96.76
Chennai	52.54	1790	24	2093	63	115	86.04
Chidambaranar	32.41	1380	15	546	16	4	44.55
Cochin	21.60	997	20	842	22	60	49.66
New Mangalore	36.57	1032	16	458	1	5	77.77
Mormugao	14.71	519	10	801	1	12	43.76
Mumbai	61.66	1959	31	4386	16	43	44.53
JNPT	63.80	2642	12	609	127	395	79.37
Kandla	92.50	2216	28	1136	16	15	121.43

Source: - Compiled from Ministry of Shipping, GoI, (2016)

Note: Y: Cargo Volume, X1: Number of Vessels Handled, X2: Number of Berths, X3: Man-Days Employed, X4: Number of Cranes, X5: Number of Other Equipment, X6: Cargo Handling Capacity.

Due to non-availability of equipment data of Kamrajar Port, the Kamrajar Port has not been included in Analysis.

4.2.2. The Empirical Analysis

Efficiency Measurement System (EMS) Software, Version 1.3 (Holger Scheel, 2000) is employed to derive the efficiency estimates of 12 major ports of India. DEA-CCR Model (for Constant Returns to Scales) has been applied to derive the relative technical efficiency of ports under analysis. On the basis of derived efficiency estimates, the relatively efficient and relatively inefficient ports are identified. The estimated efficiency scores also reveal the extent to which all inputs would need to be reduced in equal proportions to reach the optimal output level.

In case of some ports, after all inputs have been reduced in equal proportions, one or more inputs could be still reduced further without reducing the output to become optimal. (These are referred as 'input slacks' in DEA). The peer group in DEA for each port refers to the group of best practice ports with which, a relatively less efficient port is compared and less efficient port may seek to use the peer group as a guide for improving its performance.

The peer weights indicate the weighted average contribution of peer ports in making particular port better as compared to other ports. The number of times the port appears in the peer group of other ports (excluding itself) is indicated by peer count. On the basis of input slacks, peer group and peer weights, the sources of inefficiency of ports are analysed. The efficiency estimates and sources of inefficiency of ports are shown in Table 2.

Table 2:

Efficiency Estimates and Sources of Inefficiency at Inefficient Ports (2015)*

Port	Efficiency Estimate	X1 Slack	X2 Slack	X3 Slack	X4 Slack	X5 Slack	X6 Slack	Peer Group	Peer Weight	Peer Count
Kolkata	59.93%	291.69	12.91	0	0	27.92	0	Mumbai JNPT Kandla	(0.20) (0.03) (0.01)	0
Haldia	100.00%	0	0	0	0	0	0			0
Paradip	100.00%	0	0	0	0	0	0			1
Vishakhapatnam	74.82%	0	0	178.73	2.84	0.07	0	Mumbai JNPT Kandla	(0.10) (0.01) (0.55)	0
Chennai	74.15%	0	0.14	390.64	36.86	72.05	0	Mumbai Kandla	(0.14) (0.47)	0
Chidambaranar	100.00%	0	0	0	0	0	0			0
Cochin	53.97%	0	3.73	34.11	7.91	27.47	0	Mumbai Kandla	(0.04) (0.21)	0

New Mangalore	100.00%	0	0	0	0	0	0			1
Mormugao	72.55%	0	1.59	412.45	0	6.87	2.46	Paradip	(0.06)	0
								New Mangalore	(0.28)	
Mumbai	100.00%	0	0	0	0	0	0			4
JNPT	100.00%	0	0	0	0	0	0			2
Kandla	100.00%	0	0	0	0	0	0			4

Note: * Derived using Efficiency Measurement System (EMS) Software, Version 1.3.

5. Result and Discussion

On the basis of the efficiency scores obtained by major ports of India, it is revealed that Kolkata Port, Vishakhapatnam Port, Chennai Port, Cochin Port and Mormugao Port turned out to be relatively inefficient with the efficiency scores less than 1.0 (less than 100%), while Haldia Port, Paradip Port, Chidambaranar Port, New Mangalore Port, Mumbai Port, JNPT Port and Kandla Port turned out to be relatively efficient with the efficiency scores of 1.0 (100%, although the scope of improvement may still exist).

Kolkata obtained an efficiency estimate of 59.93%. This indicates that Kolkata could be able to reduce (use of) all its inputs (X1, X2, X3, X4, X5, X6) by 40.07% and still produce its output (Y1) to operate at observed best practice. This means that Kolkata can reduce (use of) its X1 by 526.52 (40.07% of 1314) to a new total of 787.48, its X2 by 13.22 (40.07% of 33) to a new total of 19.78, its X3 by 607.06 (40.07% of 1515) to a new total of 907.94, its X4 by 4.81 (40.07% of 12) to a new total of 7.19, its X5 by 32.46 (40.07% of 81) to a new total of 48.45 and its X6 by 8.45 (40.07% of 21.10) to a new total of 12.65. The peer group and peer weights columns indicate that the best practice for Kolkata is given by a weighted average of about 83.33% of Mumbai, about 12.50% of JNPT and about 4.14% of Kandla. However, as evident from the input slack columns, as well as reducing (use of) all its inputs (X1, X2, X3, X4, X5, X6) by 40.07%, Kolkata has the additional inputs (i.e. 291.69 of X1 input, 12.91 of X2 input and 27.92 of X5 input). That means to remove all the apparent waste and inefficiency relative to Mumbai , JNPT and Kandla, the Kolkata port has to reduce (use of) its inputs X1 to a new total of about 495.79 (i.e. 787.48 – 291.69), X2 to a new total of about 6.87 (i.e. 19.78 – 12 .91) and X4 to a new total of about 20.62 (i.e. 48.54 – 227.92).

Similarly, Vishakhapatnam obtained an efficiency estimate of 74.82%. This indicates that Vishakhapatnam could be able to reduce (use of) all its inputs by 25.18% and still produce its output (Y1) to operate at observed best practice. This means that Vishakhapatnam can reduce (use of) its X1 to 1453, its X2 to 18.71, its X3 to 1255.48, its X4 to 14.96, its X5 to 17.96 and its X6 to 72.40. The peer group and peer weights columns indicate that the best practice for Vishakhapatnam is given by a weighted average of about 15.15% of Mumbai, about 1.51% of JNPT and about 83.33% of Kandla. However, as evident from the input slack columns, as well as reducing (use of) all its inputs by 25.18%, Vishakhapatnam has the additional inputs (i.e. 178.73 of X3 input, 2.84 of X4 input and 0.07 of X5 input). That means to remove all the apparent waste and inefficiency relative to Mumbai, JNPT and Kandla, the Vishakhapatnam port has to reduce its inputs X3 to 1076.75, X4 to 12.12 and X5 to 17.89.

Chennai obtained an efficiency estimate of 74.15%. This indicates that Chennai could be able to reduce (use of) all its inputs by 25.85% and still produce its output (Y1) to operate at observed best practice. This means that Chennai can reduce (use of) its X1 to 1327.29, its X2 to 17.80, its X3 to 1551.96, its X4 to 46.71, its X5 to 85.27 and its X6 to 63.80. The peer group and peer weights columns indicate that the best practice for Chennai is given by a weighted average of about 22.95% of Mumbai and about 77.05% of Kandla. However, as evident from the input slack columns, as well as reducing (use of) all its inputs by 25.85%, Chennai has the additional inputs (i.e. 0.14 of X2 input, 390.64 of X3 input, 36.86 of X4 input and 72.05 of X5 input). That means to remove all the apparent waste and inefficiency relative to Mumbai and Kandla, the Chennai port has to reduce its inputs X2 to 17.65, X3 to 1161.32, X4 to 9.85 and X5 to 13.22.

Cochin obtained an efficiency estimate of 53.97%. This indicates that Cochin could be able to reduce (use of) all its inputs by 46.03% and still produce its output (Y1) to operate at observed best practice. This means that Cochin can reduce (use of) its X1 to 538.08, its X2 to 10.79, its X3 to 454.43, its X4 to 11.88, its X5 to 32.38 and its X6 to 26.81. The peer group and peer weights columns indicate that the best practice for Cochin is given by a weighted average of about 16.00% of Mumbai and about 84.00% of Kandla. However, as evident from the input slack columns, as well as reducing (use of) all its inputs by 46.03%, Cochin has the additional inputs (i.e. 3.73 of X2 input, 34.11 of X3 input, 7.91 of X4 input and 27.47 of X5 input). That means to remove all the apparent waste and inefficiency relative to Mumbai and Kandla, the Cochin port has to reduce its inputs X2 to 7.06, X3 to 420.31, X4 to 3.96 and X5 to 4.91.

Mormugao obtained an efficiency estimate of 72.55%. This indicates that Mormugao could be able to reduce (use of) all its inputs by 27.45% and still produce its output (Y1) to operate at observed best practice. This means that Mormugao can reduce (use of) its X1 to 376.53, its X2 to 7.25, its X3 to 581.12, its X4 to 0.72, its X5 to 8.70 and its X6 to 31.74. The peer group and peer weights columns indicate that the best practice for Mormugao is given by a weighted average of about 17.65% of Papadip and about 82.35% of New Mangalore. However, as evident from the input slack columns, as well as reducing (use of) all its inputs by 27.45%, Mormugao has the additional inputs (i.e. 1.59 of X2 input, 412.45 of X3 input, 6.87 of X5 input and 2.46 of X6 input). That means to remove all the apparent waste and inefficiency relative to Paradip and New Mangalore, the Mormugao port has to reduce its inputs X2 to 5.66, X3 to 168.67, X5 to 1.83 and X6 to 29.28.

It is apparent that out of efficient ports, Mumbai and Kandla are truly efficient because they are peers for 4 other ports in the sample, while JNPT appear to be peers for 2 other ports in the sample, whereas Paradip and New Mangalore appear to be peers for 1 other port in the sample, indicating the scope for them to improve their efficiency further even though they turned out to be relatively efficient.

Moreover, it is evident that ports with more number of inputs (than actually required for handling/producing given output) turn out to be relatively inefficient. Kolkata Port, Vishakhapatnam Port, Chennai Port, Cochin Port and Mormugao Port depicted that most of the ports turned out to be inefficient mostly because they had higher Number of Berths, Man-Days Employed, Number of Cranes and Number of Other Equipment than actually required to produce/handle the given output (Cargo Volume). However, optimum allocation by reducing the (use of) excess of inputs for handling the given output places the relatively inefficient ports in a better position towards increasing the efficiency.

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