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Data Envelopment Analysis (DEA) Based Study of Major Sea Ports of India

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ABSTRACT

India is one of the biggest peninsulas in the world. A major part of trading, both by volume and value, is done through maritime transport in India. There are twelve major government owned ports that service this transport. Efficiency evaluation of these ports is crucial for the operators and managers to analyse their performance for further improvements. The present study uses the non parametric efficiency evaluation technique of data envelopment analysis (DEA) to measure the performance of these ports for the year 2019-2020. Technical, Pure Technical, scale and super efficiencies have been evaluated for the twelve major ports. Three out of twelve ports turned out to be efficient when evaluated by using the constant returns to scale model and six turned to be efficient when evaluated using variable returns to scale model. In order to give benchmarks to the inefficient ports, potential improvements in the input and output variables have also been discussed. It was observed that Kamarajar port in Tamil Nadu is the best performer while Mormugao in Goa is the least.

Key words: Data Envelopment Analysis, Efficiency evaluation, Sea Ports, Benchmarking

1. INTRODUCTION

Seaports are economic and service provision units of remarkable importance because they act as a place for the interchange of two transport modes by rail or road. They are the most important sectors of commerce and transportation of any country. For identification of opportunities for success and growth in today's competitive environment, it is necessary for ports to evaluate their performance in all aspects [12]. India being a peninsula has an advantage of being surrounded by Indian ocean, Arabian sea and Bay of Bengal. India has a coastline of around 7517 Kms with 12 major ports and 212 non-major ports. Coasts of India are extended along 9 States and 4 Union Territories. The coastal states of India are divided in west and east coasts. Gujrat, Maharashtra, Goa, Karnataka are the states along the West Coast and Tamil Nadu, Andhra Pradesh, Orrisa, West Bengal are the states along the East Coast. 12 major ports of India are Mumbai, J.L. Nehru, Mormugao, New Mangalore, Deen Dayal, Cochin, V.O. Chidambaramar, Chennai, Kamarajar, Visakhapatnam, Paradip, SMP (Haldia Doc Complex) [10].

The major part of the budget allocated to the transport sector is taken up in maintaining the 12 major ports. Major Port Trust Act, 1993 & Indian Ports Act of 1908 authorises Ministry of Shipping, Government of India to manage these ports. Researchers in the field of management are attracted to study of the ports. Efficiency concern is the main aspect of performance of Indian ports. Policy makers have special interest in analysing how efficiently, a particular port is performing as it forms a crucial parameter to access the quality of a port.

In this study efficiency of sea ports in India is estimated and the ports have been ranked as per their performance. Data Envelopment Analysis (DEA) has been used for efficiency evaluation. DEA is a non parametric linear programming-based technique that evaluates the efficiency of any decision-making unit as a ratio of its weighted sum of outputs to weighted sum of inputs.

Literature Survey

Researchers across the world have developed models and tools to measure the efficiencies of sea ports using DEA. Various approaches have been used for this analysis.

The role of ports in the growth of a nation's international link, trade, and economy was studied [3]. According to them the level of performance and efficiency of port determines, to a large extent, a nations international competitiveness. Further, the performance of any sea port depends on its infrastructure and services.

Port efficiency and competitive environment of 23 ports across the world was studied [5]. According to them, port efficiency is important for trade, economic development of the region and to see the challenges in international competitive environment. The DEA empirical analysis with two output variables and six input variables, has been illustrated by them for their study.

The variation of efficiency of ports from country to country and specially from region to region was studied [7]. According to them some Asian ports (Singapore, Hongkong) are the most efficient ports in the world, while some of the inefficient ports are in Africa (Nigeria, Malawi).

The efficiency with respect to containerized cargoes across ports recognised for their high level of performance in Asia and Europe was studied [6]. The study used two outputs and six input measures of port performance for sixteen container ports for year 1996. Empirical results for DEA models ranked ports for their efficiency.

However, in India, very few researchers have studied the efficiencies of sea ports.

The efficiency of Indian ports by making use of DEA was studied [8]. Main objective in their study was to bring out the actual working and performance of the ports sector in India. They used seven input and single output variables in their study. Results of their study reveal a complete efficiency picture of Indian ports for the year 2005-06. Port input variables used were number of cranes, number of berths, storage area in Sq. metres, average pre berthing time in days and average turnaround time in days. The single output variable taken by them was cargo volume in million tonnes.

The productive index and efficiency change of sea ports in India by using DEA was studied [9]. In this study, they used Malmquist DEA technique to compute technical efficiency for data available for the year 1996–97 to 2013-14. Seven port input variables used in this study are land, labour, number of cranes, number of berths, number of other equipment etc. Two output variables used in their study are number of vessels handled and volume of cargo traffic in million tonnes.

The present study evaluates the efficiency of 12 major ports with 3 inputs & 1 output variables. Super efficiency models of DEA are used to give a complete ranking of these ports.

The remainder of this paper is organised in the following manner:

Section 2 deals with the theoretical framework used in the study. Data sources, variables, mathematical models, and analysis of variables have been discussed in this section.

Section 3 describes the results and discussions of the analysis carried out.

Section 4 presents the conclusion and future scope of the study presented.

2. METHODOLOGY

2.1 Data and Variables

Annual data relating to input variable (Productive factors) and output variables (Production) of 12 major ports of India have been used for this study. In this study data of 12 major ports of India for the Year 2019-2020 has been used. The 12 major ports studied are Deen Dayal, Mumbai, J.L. Nehru, Mormugao, New Mangalore, Cochin, V.O. Chidambaramar, Chennai, Kamarajar, Visakhapatnam, Paradip and SMP Haldia [11]. These ports are spread across the eastern and western coasts of India, six ports each being on both sides of the coast. Mumbai, Chennai and Mormugao are the oldest ports, being more than a century old.

Three input and one output variable has been used for analysis. The input variables are berth occupancy (in percentage), operating expenditure (Rs. in lakh), Manpower (in numbers) and the output variable taken is operating income (Rs. in lakh).

The required panel data for year 2019-20 was sourced from secondary sources. The major sources of our data collection come from "Basic Ports Statistics of India. 2019-20, Published by Ministry of Shipping, Ports and Waterways, Government of India" and "Major Ports of India, a profile published by Indian Port Association, New Delhi".

The non parametric estimation is done by using DEA solver software. Table 1 below shows the correlation between variables under the study:

Table 1: Coefficient of determination between the variables

S. No.	Input	Output (Operating income)
1.	Berth Occupancy (in percentage)	0.00195638
2.	Operating Expenditure (Rs. in lakh)	0.76954124
3.	Manpower (in numbers)	0.12412304

It can be observed that all the three input variables are correlated positively with output variable. Further the variables under study enjoys a cause-and-effect relationship thereby ensuring that the choice of input and output variables is correct. These variables have also been used by the previous studies conducted in this area.

2.2 MATHEMATICAL MODELS

DEA is a well-established tool to make comparisons among decision making units (DMUs). In this study non parametric technique is used to evaluate efficiencies of the Indian major ports. The mathematical models used in the study are

Charnes, Cooper & Rhodes (CCR) Model [1]:

This model was suggested by Charnes, Cooper and Rohdes [1] which is concerned with the estimation of technical efficiency. This model uses a constant return to scale assumption. Let there be 'n' DMUs, each with 'm' inputs and 's' outputs. For DMU 'o' the basic CCR output maximization, which is also called CRS model is outlined as follows:

$$\max h_o = \frac{\sum_{r=1}^{s} u_r y_{rjo}}{\sum_{i=1}^{m} v_i x_{ijo}}$$

$$\text{subject to: } \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \text{ for each unit '}j\text{'} \qquad \text{(M1)}$$

$$u_r,\ v_i \geq 0$$

where u_r = weight given to output 'r'.

where v_i = weight given to input 'i'.

The weights u_r and v_i are applied to outputs y_{rj} and inputs x_{ij} that are chosen to maximize the efficiency score h_o for DMUo. The above is a fractional programming problem which is converted into linear programming problem by normalizing the denominator as $\sum_{i=1}^{m} v_i\ x_{ijo} = 1$ and adding it as an additional constraint. The model thus becomes:

$$\max h_o = \sum_{r=1}^{s} u_r\ y_{rjo}$$

$$\text{subject to: } \sum_{i=1}^{m} v_i\, x_{ijo} = 1 \qquad \text{(M2)}$$

and

$$\sum_{r=1}^{s} u_r\, y_{rjo} - \sum_{i=1}^{m} v_i\, x_{ijo} \leq 0$$

$$u_r\,,\ v_i \geq 0$$

The above model is executed once for each participating DMU resulting in the optimal weights being determined for each DMU. Each DMU selects input and output weight that maximizes its efficiency score. A DMU getting an efficiency score of unity is consider to be efficient and else it is inefficient. The efficiency computed using this model is called technical efficiency (TE).

Banker, Charnes and Cooper (BCC) Model [2]:

Banker, Charnes and Cooper [2] developed the BCC Model. It is also referred as variable returns to scale (VRS) model. Under variable returns to scale assumption the convexity constraint is added with the CCR model. Mathematically, the BCC model is:

$$\max h_o = \sum_{r=1}^{s} u_r\ y_{rjo} - u_o$$

$$\text{subject to: } \sum_{i=1}^{m} v_i\, x_{ijo} = 1 \qquad \text{(M3)}$$

and

$$\sum_{r=1}^{s} u_r\, y_{rjo} - u_o - \sum_{i=1}^{m} v_i\, x_{ijo} \leq 0$$

u_o is free in sign

$u_r > 0$, $r = 1, 2 \ldots s$

$v_i > 0$, $i = 1, 2 \ldots m$

The above model is solved for each DMU under study. Each DMU is allowed to choose its input and output weights that maximizes its efficiency score. The efficiency computed using this model is known as Pure Technical Efficiency (PTE).

Scale Efficiency (SE):

Scale efficiency is defined as the ratio of technical efficiency to pure technical efficiency i.e. the ratio of efficiency score of the CCR model to the BCC model. This measure of efficiency gives information on the scale of operations of the DMUs under study.

Super Efficiency Model:

DEA is advantageous to distinguish between the efficient and inefficient units in the data set. However, it is weak in discriminating between the efficient units. In order to give a complete ranking structure, Super efficiency model of DEA used. While evaluating this efficiency the target DMU is not included in the constraint set. The CCR model M1 as defined above is then used to compute the efficiency scores. The units in this model can thus attain a score greater than 1 also. Hence, units in the data set can be ranked amongst themselves as per their performance.

3. RESULTS AND DISCUSSIONS

Performance evaluation and benchmarking are widely used techniques to identify and to improve the performance and to increase productivity. The present study is an attempt to take stock of the Indian marine port scenario. According to DEA technique DMUs with score 1 are considered as efficient and DMUs showing score less than 1 are considered as inefficient.

Table 2: Efficiency Scores

S. No.	DMUs/ Ports	Technical Efficiency	Pure Technical Efficiency	Super Efficiency	Scale Efficiency	Rank
1.	Deen Dayal	0.967264	1	0.967264	0.967264	9
2.	Mumbai	1	1	1.372053	1	3
3.	J.L. Nehru	1	1	1.44851	1	2
4.	Mormugao	0.472798	0.530045	0.472798	0.891995	12
5.	New Mangalore	0.716399	1	0.716399	0.716399	8
6.	Cochin	0.594971	0.631778	0.594971	0.941740	10
7.	V.O Chidambaramar	0.703461	0.707399	0.703461	0.994433	9
8.	Chennai	0.582496	0.63865	0.582496	0.912073	11
9.	Kamarajar	1	1	3.342753	1	1
10.	Vishakapatnam	0.888326	0.902229	0.888326	0.984590	6
11.	Paradip	0.966249	1	0.966249	0.966249	5
12.	SMP Haldia	0.840578	0.906131	0.840578	0.927656	7

Table 2 above lists the efficiency scores of the 12 units under study by using the mathematical models discussed in the previous section. DMU '9' Kamarajar port is most efficient, having rank 1 among 12 major ports. J.L. Nehru port is efficient with rank 2 and Mumbai port is also efficient port with rank 3 among 12 major ports of India. Mormugao port is most inefficient port with rank 12 among 12 major ports of India.

Benchmarking:

The technique of DEA helps in identifying efficient and non-efficient DMUs. Efficient DMUs that lie on the frontier constitute a peer set for the inefficient DMUs. These peer sets define the benchmarks for the inefficient DMUs so that they can improve their efficiency. The following Table 3 gives the projections for potential improvements in the input and output variables for the inefficient units.

Table 3: Projection Table

S. No.	DMU I/O	1/Score Data	Projection	Difference	%
1	1	1.033844			
	Birth Occupancy (in Percentage)	69.1	69.1	0	0.00%
	Operating Expenditure (Rs. in Lakh)	71404	71404	0	0.00%
	Manpower (Numbers)	2339	1034.181	-1304.82	-55.79%
	Operating Income (Rs in Lakh)	172815	178663.7	5848.68	3.38%
2	2	1			
	Birth Occupancy (in Percentage)	32.2	32.2	0	0.00%
	Operating Expenditure (Rs. in Lakh)	120570	120570	0	0.00%
	Manpower (Numbers)	6429	6429	0	0.00%
	Operating Income (Rs in Lakh)	166234	166234	0	0.00%
3	3	1			
	Birth Occupancy (in Percentage)	50.3	50.3	0	0.00%
	Operating Expenditure (Rs. in Lakh)	86913	86913	0	0.00%
	Manpower (Numbers)	1473	1473	0	0.00%
	Operating Income (Rs in Lakh)	189261	189261	0	0.00%
4	4	2.115067			
	Birth Occupancy (in Percentage)	84.8	59.26828	-25.5317	-30.11%
	Operating Expenditure (Rs. in Lakh)	24632	24632	0	0.00%
	Manpower (Numbers)	1517	132.2837	-1384.72	-91.28%
	Operating Income (Rs in Lakh)	43117	91195.33	48078.33	111.51%
5	5	1.39587			
	Birth Occupancy (in Percentage)	40.3	40.3	0	0.00%
	Operating Expenditure (Rs. in Lakh)	27284	27284	0	0.00%
	Manpower (Numbers)	626	307.1274	-318.873	-50.94%
	Operating Income (Rs in Lakh)	57214	79863.32	22649.32	39.59%
6	6	1.680754			
	Birth Occupancy (in Percentage)	58.5	58.5	0	0.00%
	Operating Expenditure (Rs. in Lakh)	35567	35567	0	0.00%
	Manpower (Numbers)	1394	362.5717	-1031.43	-73.99%
	Operating Income (Rs in Lakh)	64903	109086	44183	68.08%
7	7	1.421542			

	Birth Occupancy (in Percentage)	47.7	47.7	0	0.00%
	Operating Expenditure (Rs. in Lakh)	25410	25410	0	0.00%
	Manpower (Numbers)	691	221.6128	-469.387	-67.93%
	Operating Income (Rs in Lakh)	58290	82861.7	24571.7	42.15%
8	8	1.716749			
	Birth Occupancy (in Percentage)	44.6	44.6	0	0.00%
	Operating Expenditure (Rs. in Lakh)	57821	57821	0	0.00%
	Manpower (Numbers)	3953	909.3926	-3043.61	-76.99%
	Operating Income (Rs in Lakh)	78755	135202.5	56447.54	71.67%
9	9	1			
	Birth Occupancy (in Percentage)	45.7	45.7	0	0.00%
	Operating Expenditure (Rs. in Lakh)	18993	18993	0	0.00%
	Manpower (Numbers)	102	102	0	0.00%
	Operating Income (Rs in Lakh)	70318	70318	0	0.00%
10	10	1.125713			
	Birth Occupancy (in Percentage)	57.1	57.1	0	0.00%
	Operating Expenditure (Rs. in Lakh)	65201	65201	0	0.00%
	Manpower (Numbers)	3150	982.3344	-2167.67	-68.81%
	Operating Income (Rs in Lakh)	140479	158139	17660.04	12.57%
11	11	1.03493			
	Birth Occupancy (in Percentage)	73.4	73.4	0	0.00%
	Operating Expenditure (Rs. in Lakh)	66692	59328.2	-7363.8	-11.04%
	Manpower (Numbers)	758	758	0	0.00%
	Operating Income (Rs in Lakh)	156326	161786.4	5460.404	3.49%
12	12	1.189658			
	Birth Occupancy (in Percentage)	66.5	66.5	0	0.00%
	Operating Expenditure (Rs. in Lakh)	97648	81171.21	-16476.8	-16.87%
	Manpower (Numbers)	1252	1252	0	0.00%
	Operating Income (Rs in Lakh)	162271	193047	30775.96	18.97%

It can be observed that DMU '9' Kamarajar port has no need of any improvement because it is the most efficient unit. Infact, all the efficient ports form the peer group and hence do not need any improvement in their variables. Mormugao port is the least efficient unit and hence needs to change its berth occupancy and manpower to increase its efficiency. Deen Dayal port must have to reduce manpower to increase its efficiency. New Mangalore port also must have to reduce its manpower to increase its efficiency. Paradip and SMP Haldia ports must have to reduce their operating expenditure to increase their efficiency.

4. CONCLUSION

The main role of a port is to transfer goods between two transport modes. The assessment of performance of a port must be to address the efficiency of the overall port system [4]. Therefore, addressing the efficiency of ports should be the main aspect of benchmarking of the performance of today's Indian port.

Efficiency is the core for policy makers hence, it needs to be quantified objectively in order to help the port sector to grow further. This study made use of Data Envelopment Analysis to evaluate efficiency of Indian ports. In this study, The CCR, BCC and Super efficiency models were used to compute efficiency and give a complete ranking of units under study.

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