



# Performance Analysis and Classification of the Ports in Gulf Countries Using Data Envelopment Analysis

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## ABSTRACT

The study assesses relative efficiency and performance characteristics of the major ports in gulf countries using data envelopment analysis (DEA). Ports play key role in economic activities of these countries. The study reveal that technical efficiency of the ports in the region varies widely with mean constant and variable return to scale of 67.5 and 91 percent, respectively. Port Jabel Ali in UAE is identified as the benchmark for most of the inefficient ports indicating that the inefficient ports of the region should follow operational strategies of Port Jabel Ali. Also, all the inefficient ports of the region demonstrate increasing return to scale implying that their performance may improve with the scale of operation. Policy makers may consider investment to enhance operational scope of these ports.

**Keywords:** Ports; Data Envelopment; Analysis Efficiency; Scale.


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## INTRODUCTION

Ports are essential entity in international trade and commerce of any country. They perform as indispensable intermodal connectivity node facilitating exports and imports for industrial and commercial activities. As the intermodal transfer node between waterway and land surface modes, port efficiency is vital for global logistic operation. Moreover, operational efficiency of the ports critically affect regional productivity and competitiveness (Wu and Goh, 2010 and Kutin et al., 2017). Liu (2008) suggest that port efficiency is an important indicator of regional economic activity. Jiang and Li (2009) recommend to monitor port performance for microeconomic development policy processing.

Review of previous studies related to port performance reveal that most of them primarily concentrated on European or East Asian countries. Also, majority of these studies focused on container services (Cullinane et al., 2006). Lack of data availability may be one of the major reasons of scarcity of literature on port performance in gulf countries (Al-Eraki et al, 2010). Particularly for the gulf countries, performance of the ports are very significant as their economy heavily relies on exports and imports. Zahran et al (2015) compared performance of Saudi ports with ports of other countries using revenue as output variable. The authors reported widely varied efficiencies for different model specifications and suggested for further studies in this regard.

Port functionality and management is highly complex. Also, analysis of port performance becomes more challenging due to unavailability of data, lack of transparency and varied operational procedures (Zahran et al., 2017). Usually port authorities rely on wide range of modelling frameworks for port operational management and planning (Zahran et al., 2015). Parametric and non-parametric approaches are the two broad categories of modeling framework that are extensively used in port performance analysis. Among the parametric methods stochastic frontier analysis (SFA) is the most

frequently used parametric approach (Medda and Liu, 2013 and Sarriera et al, 2013). Among the non-parametric approaches application of Data Envelopment Analysis (DEA) is highly prevalent (Hung et al., 2010, Demirel et al., 2012, Schoyen and Odeck, 2013, Ding et al, 2015).

This study analyzes relative efficiency of nine major ports in gulf region, identifies the efficient ports in the region and examine their performance characteristics. Classical Data Envelopment Analysis (DEA) approach is used to measure efficiency and performance indicators, assess production frontier, and evaluate intervention policies for performance improvement. The study contributes in assisting the policy makers to identify performance limitations and provide policy directives for future development.

## METHODOLOGY

As mentioned earlier that the methods for performance benchmarking of production entity is usually categorized into parametric and non-parametric framework. Parametric methods, like Stochastic Frontier Analysis (SFA) and Free Disposable Hull (FDH), are based on the assumption of particular population distribution. But, researchers observed that such preemptive assumptions might be very restrictive (Xu and Ishiguro, 2019). Nonparametric approaches, like Data Envelopment Analysis (DEA), do not require such restriction and models can be calibrated using few samples. Due to its simple and flexible structure DEA has evolved as the most suitable tool for assessing efficiency of production entities (Zahran et al.,2015).

Based on the concepts initiated by Debreu (1951), Farrel (1957), Charnes et al. (1978), and Charnes and Cooper (1984) defined the general framework of DEA as an optimization method based on mathematical programming. Specific implementations of the approach vary widely that include multiplier or envelopment structure, input or output orientations, and constant or variable return to scale. Basic DEA approach, in multiplier form, estimates the efficiency of a set

of production unit as the ratio between weighted inputs and outputs stratifying the constraint that the maximum value of the efficiency must not exceed 1. Recently the envelopment form has

become very popular due to its computational benefit (Kutin et al, 2017). Mathematical framework for efficiency assessment of DEA in multiplier form is shown below.

$$\begin{aligned} \max h_{u,v}^{j_0} &= \frac{\sum_{r=1}^s u_r y_{rj_0}}{\sum_{i=1}^m v_i x_{ij_0}} \\ \text{s.t. } \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} &\leq 1, \quad j = 1, \dots, j_0, \dots, n \\ u_r, v_i &\geq \epsilon \quad \forall r, i \end{aligned} \tag{1}$$

Where  $u$  and  $v$  are the weights corresponding to  $s$  outputs ( $y$ ) and  $m$  inputs ( $x$ ) respectively. This model may be solved for all decision-making units ( $n$ ) to maximize its relative efficiency. It can be further simplified into linear programming

form for computational purpose. The model can also be expressed as input oriented envelopment form with constant return to scale (CRS) as follows.

$$\begin{aligned} \text{Min}_{\theta, \lambda} \quad & \theta, \\ \text{st} \quad & -\mathbf{q}_i + \mathbf{Q}\lambda \geq \mathbf{0}, \\ & \theta \mathbf{x}_i - \mathbf{X}\lambda \geq \mathbf{0}, \\ & \lambda \geq \mathbf{0} \end{aligned} \tag{2}$$

Notation:  $K$  inputs,  $M$  outputs,  $i$  firms  
 $x_i$  is  $K \times 1$  vector of inputs of  $i$ -th firm  
 $q_i$  is  $M \times 1$  vector of outputs of  $i$ -th firm  
 $X$  is a  $K \times I$  input matrix,  $Q$  is a  $M \times I$  output matrix

$\theta$  is a scalar (=TE),  $\lambda$  is a  $I \times 1$  vector of constants  
 It is extended to variable return to scale (VRS) by incorporating the following constraint in Equation 2 (Banker et al, 1984).

$$\sum \lambda = 1 \tag{3}$$

Besides efficiency calculation, outputs of the DEA provide useful information regarding shadow price of the input and output resources through the multipliers of model in Equation 1 or slacks of envelopment form in Equation 2 (Alam et al, 2004). Also, for any decision-making entity ( $j_0$ ) the optimal values of  $\lambda$  identifies the set of corresponding efficient entities, called reference set or peer group, and define the production frontier.

The conventional forms DEA methodology do not incorporate uncertainty or errors in input and output values. To assess confidence interval of efficiency estimates DEA framework can be further extended by using bootstrap technique and fuzzy framework (Hatami-Marbibi et al, 2014).

In order to extract useful information from DEA model it should formulated with specific purpose, the decision-making units with their inputs and outputs should be clearly identified, and the

model should be appropriately oriented (Almawsheeki and Shah, 2015 and Cook et al, 2014).

**VARIABLES AND DATA SETS**

**Input and Output Variable**

Selection of variable is the key step in performance investigation that should reflect the objective of the analysis and underlying production mechanism or function. Previous studies suggest that land, labor and capital are

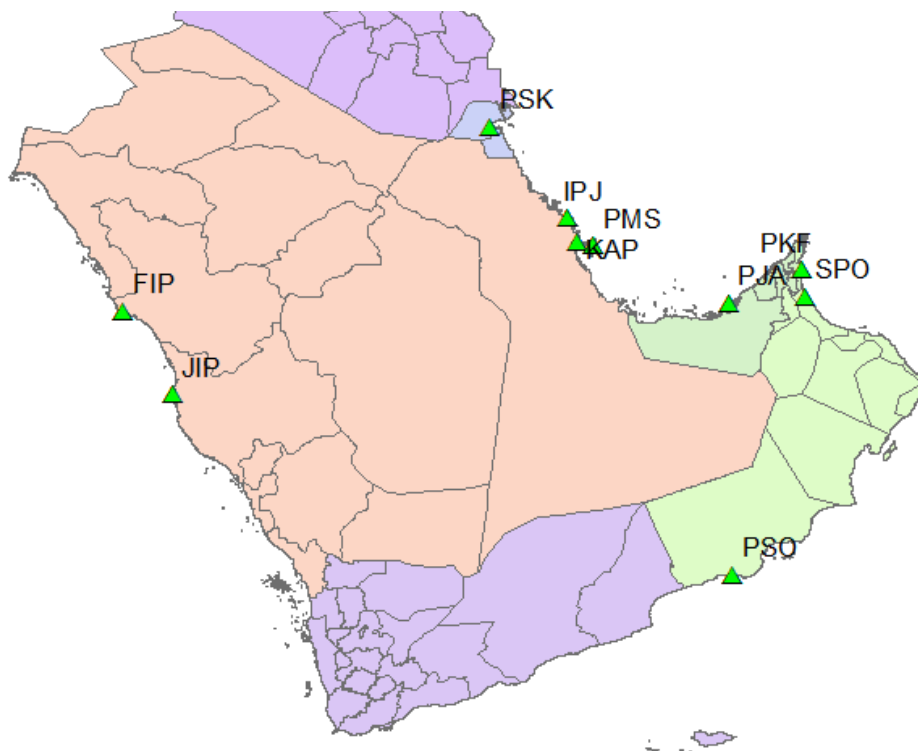
principal factors affecting productivity of the ports. Usually labor data is very difficult to collect and is not generally reported in public reports. In this study, we analyzed port efficiency on the basis of land and infrastructure (no of berths and channel depth) as input variable, while container and cargo throughputs as port outputs (Almawsheeki and Shah, 2015 and Panayides et al, 2009). Statistical parameters are summarized in Table 1 below.

**Table 1 Summary statistics of the variables for efficiency analysis**

Variables	Mean	Maximum	Minimum
Berths (No)	28.2	67	2
Depth (m)	13.46	18	9.6
Area (Thousand sq.m)	7.47	29.02	1.76
Cargo (Millon Ton)	32.68	170	0.62
Container (Million)	3.02	13.6	0.12

The basic requirement of performance analysis is the identification of decision making units. This study analyzes the major ports of the gulf countries that include Saudi Arabia, United Arab

Emirates and Oman. The nine ports those are included in the study are shown in Figure 1 and described in Table 2 below.



**Figure 1. Map showing location of the ports included in the study.**

**Table 2. Ports of Gulf Countries included in the Study**

ID	Country	Ports
FIP	Saudi Arabia	King Fahd Industrial Port Yanbu
JIP	Saudi Arabia	Jeddah Islamic Port
KAP	Saudi Arabia	King Abdulaziz Port
IPJ	Saudi Arabia	Industrial Port Jubail
SPO	Oman	Sohar Port
PSO	Oman	Port Salalah
PJA	United Arab Emirates	Port of Jabel Ali
PKF	United Arab Emirates	Port Khor Fokkan
PMS	Bahrain	Port of Mina Salman
PSK	Kuwait	Port of Shuwaikh

For the DEA based efficiency analysis we employed input oriented DEA model for both constant (CRS) and variable (VRS) return to scale. We analyzed efficiencies for multiplier and envelopment forms to assess shadow prices and slacks of the input variables. We used R software packages to analyze efficiency and associated indicators (R Core Team, 2019).

### EMPIRICAL ANALYSIS

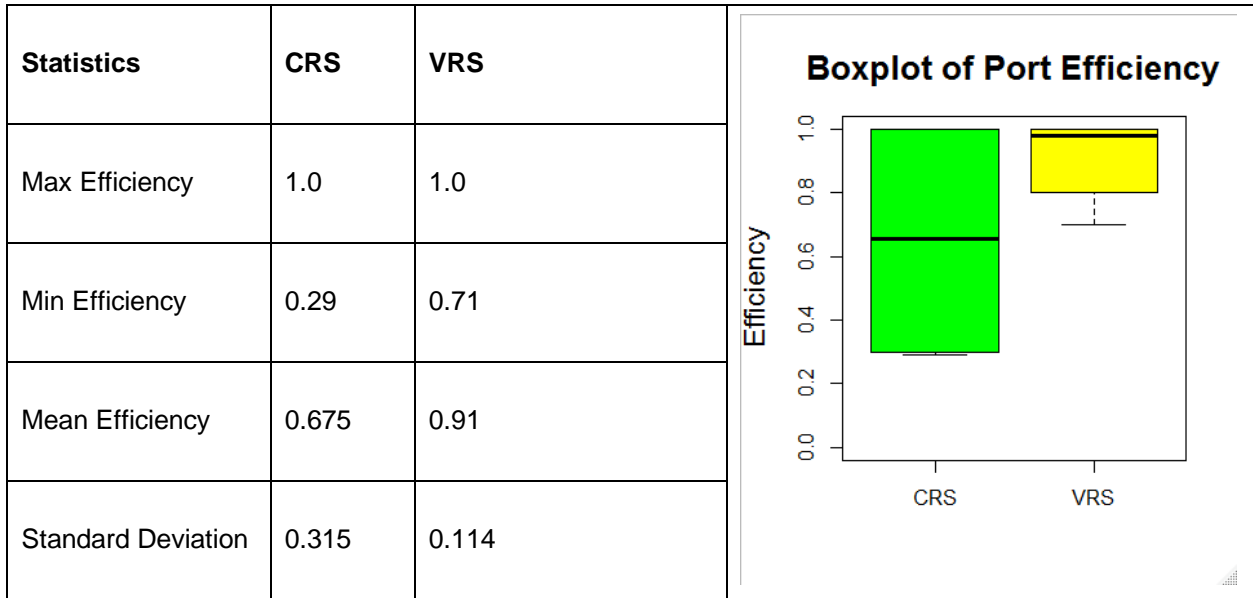
This section presents the results of analyzes that include technical efficiency of the major ports in gulf countries, scale of production, shadow prices, and slacks corresponding to the input variables. Also, we identified the benchmarks for the inefficient ports and confidence interval of efficiency values.

### Relative Technical Efficiency Score of Ports in Gulf Countries

Efficiency scores for the ports is presented in Table 3 and Figure 2 including benchmarks and return to scale information. It is observed that the efficiencies of the ports in gulf region varies widely with mean efficiencies of 67.5 and 91 percent for CRS and VRS, respectively. Also the CRS efficiencies demonstrate wider variation. Ports Jabel Ali, King Abdulaziz, Salaha and Sohar are performing efficiently, while Port Khor Fokkan, Industrial Port Jubail and Port Mina Salman are the most inefficient ports in the region. All the inefficient ports demonstrate increasing return to scale.

**Table 3. Efficiency scores of the ports**

DMU	Efficiency (CRS)		Efficiency (VRS)	Scale Efficiency	Benchmarks/References	Lamda sum	Return to Scale
FIP	0.55	Inefficient	0.70	0.79	PJA	0.25	Increasing
JIP	0.77	Inefficient	0.79	0.97	KAP,PJA,SPO	0.86	Increasing
KAP	1.00	Efficient	1.00	1.00	KAP	1.00	Constant
IPJ	0.30	Inefficient	0.80	0.37	PJA,SPO	0.35	Increasing
SPO	1.00	Efficient	1.00	1.00	SPO	1.00	Constant
PSO	1.00	Efficient	1.00	1.00	PSO	1.00	Constant
PJA	1.00	Efficient	1.00	1.00	PJA	1.00	Constant
PKF	0.29	Inefficient	0.86	0.34	PJA,SPO	0.18	Increasing
PMS	0.30	Inefficient	1.00	0.30	PJA	0.01	Increasing
PSK	0.55	Inefficient	0.96	0.57	KAP,PJA,SPO	0.49	Increasing



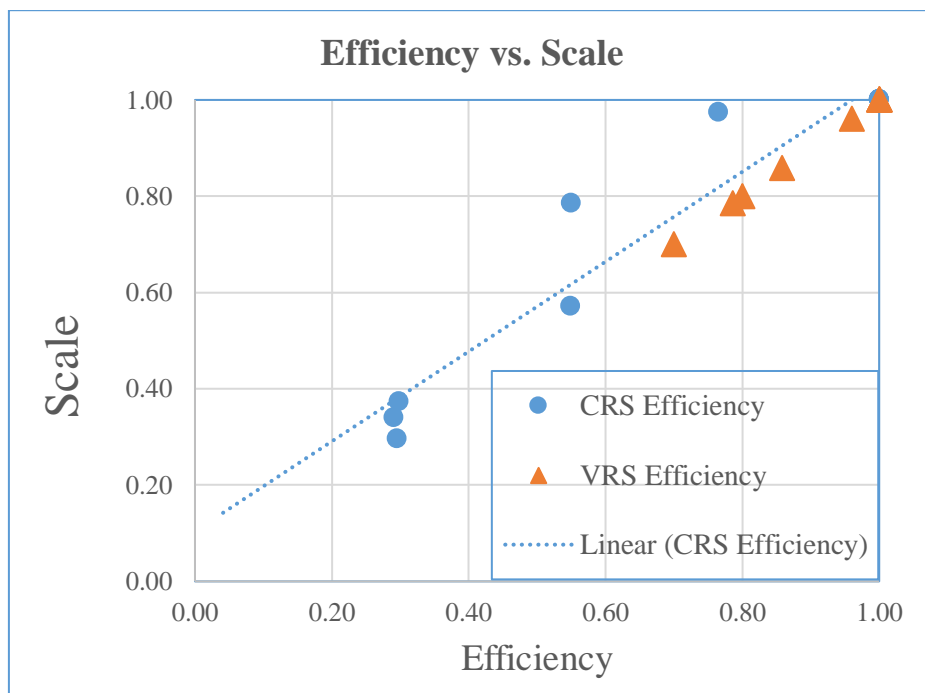
**Figure 2. Summary of Port Efficiency Analysis**

**Benchmarks**

Table 3 shows the benchmarks or reference decision making ports corresponding to the inefficient ports. The benchmarks identify relevant best practice peers for the inferiorly performing DMUs. The inefficient ports can track the relevant benchmarks to improve their performance. Table 3 reveals that Port Jabel Ali is identified as the benchmarks for most of the inefficient ports of the region.

**Scale Efficiency and Return to Scale**

As mentioned earlier that the ratio between CRS and VRS efficiencies provide information regarding scale efficiency. From Table 3 it is evident that all the inefficient ports of CRS analysis show increasing return to scale. Also, as shown in Figure 3 overall technical efficiency is highly correlated with scale efficiency for both CRS and VRS cases.



**Figure 3. Technical Efficiency vs. Scale**

## Weights and Slack Variable Analysis

Weights of input and output variables of DEA in multiplier form provides information regarding resource constraint and shadow price. Also, analysis of slack variables provides information for the inefficient units to become efficient by minimizing the input resources (for input oriented models) or maximizing the outputs (for output oriented models). Table 4 shows the measured and CRS target values of the input

variables. The difference between these values provide information about slack (negative gain) in input for variables. As shown in Table 4 the inefficient ports can improve their performance by reducing the inputs by the amounts shown in Gain/Slack column. The input and output weights (Table 5) provides information about shadow/marginal prices of the input and output resources. Larger values of the weights imply higher rate of return for improvement corresponding to the relevant resources.

**Table 4. Measured and Target Inputs and Slacks of DEA (Envelopment Form)**

DMU	Input (Measured)			Input (Target)			Gain/Slack		
	Berths	Depth	Area	Berths	Depth	Area	Berths	Depth	Area
FIP	30.0	15.0	16.7	16.5	3.9	7.1	-13.5	-11.1	-9.6
JIP	58.0	16.0	10.5	30.5	12.2	8.1	-27.5	-3.8	-2.5
KAP	39.0	18.0	2.0	39.0	18.0	2.0	0.0	0.0	0.0
IPJ	16.0	12.0	4.4	4.8	3.5	1.3	-11.2	-8.5	-3.1
SPO	10.0	9.6	2.1	10.0	9.6	2.1	0.0	0.0	0.0
PSO	31.0	16.0	2.9	31.0	16.0	2.9	0.0	0.0	0.0
PJA	67.0	16.0	29.0	67.0	16.0	29.0	0.0	0.0	0.0
PKF	8.0	12.0	2.1	2.3	1.8	0.6	-5.7	-10.2	-1.5
PMS	2.0	10.0	1.8	0.6	0.1	0.3	-1.4	-9.9	-1.5
PSK	21.0	10.0	3.2	8.6	5.5	1.8	-12.4	-4.5	-1.4

**Table 5. Weights of inputs and outputs of DEA (Multiplier Form)**

DMU	Berths	Depth	Area	Cargo	Container
FIP	0.033	0.000	0.000	0.000	0.164
JIP	0.000	0.009	0.081	0.010	0.065
KAP	0.016	0.000	0.189	0.039	0.000
IPJ	0.057	0.000	0.019	0.000	0.322
SPO	0.015	0.048	0.185	0.000	0.526
PSO	0.009	0.027	0.104	0.000	0.295
PJA	0.002	0.000	0.029	0.006	0.000
PKF	0.115	0.000	0.037	0.000	0.647
PMS	0.500	0.000	0.000	0.000	2.463
PSK	0.000	0.026	0.232	0.027	0.185

## Effect of Data Uncertainty on Efficiency Calculation

Conventional DEA model assumes that the data used for efficiency calculation is accurate and does not allow for any stochasticity. Considering that the information used for efficiency calculation may contain noise, the DEA modeling framework is extended to incorporate

fuzzy concept (Leon et al, 2003). Assuming symmetric triangular fuzzy structure with 10 percent extent of variation for the input and output variables, efficiencies of the DEA model (input oriented CRS) is estimated for different alpha-cuts which are shown in Table 6 below. The table shows that estimated efficiencies remain quite stable.

**Table 6. Efficiency of the ports using Fuzzy-DEA**

DMU	Efficiency			
	DEA-CRS	Fuzzy DEA-CRS ( $\alpha=0$ )	Fuzzy DEA-CRS ( $\alpha=0.5$ )	Fuzzy DEA-CRS ( $\alpha=1$ )
FIP	0.550	0.554	0.552	0.550
JIP	0.765	0.765	0.765	0.765
KAP	1.000	1.000	1.000	1.000
IPJ	0.298	0.301	0.300	0.298
SPO	1.000	1.000	1.000	1.000
PSO	1.000	1.000	1.000	1.000
PJA	1.000	1.000	1.000	1.000
PKF	0.291	0.308	0.300	0.291
PMS	0.296	0.353	0.324	0.296
PSK	0.549	0.549	0.549	0.549

## CONCLUSION

This study focused on assessing relative efficiency of the major ports in gulf countries with the objective of improving their performance and assist policy makers in formulating strategic policies. DEA framework was used to analyze 10 ports in five countries of the region. Analyses revealed that there exists wide variation in performance efficiencies of the ports considered in the study. Among the 10 ports analyzed, only four performed efficiently that include Port Jabel Ali in UAE, King Abdulaziz Port in Saudi Arabia, and Salalah and Sohar Port in Oman. Although Jeddah Islamic Port is one of the largest ports of the region, it performed incompetently. All the inefficient ports revealed increasing return to scale implying that their performance may improve with increased activity level. Port Jabel

Ali (PJB) was identified as the benchmark for most of the inefficient ports implying that its production policy may be pursued to improve the performance of these inefficient ones. Fuzzy analysis reveal that estimated efficiencies were reasonably stable.

For future research, other smaller ports should be included in the study. Also to have better understanding of functional performance, these ports should be analyzed on the basis of their activity concentration like container, cargo, and petroleum product. As the current study was conducted on cross-sectional data, it can be extended to analyze performance improvement trend through incorporating panel data in the analysis. Moreover, performance of the ports in gulf region should be compared with the same of



other regions in order to assess their global competitiveness.

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