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Investigation of Iranian Ports Performance in Oil Exchanges Using Data Envelopment Analysis

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ABSTRACT

In this study, the performance and efficiency of 12 ports in the Persian Gulf, Oman and Caspian seas in Iran is evaluated using data envelopment analysis (DEA) method. DEA allows comparing the efficiency in revenue generation of ports with different economies. Two different modeling approaches were presented in this study; based on relating earnings to port operational capability and activity, and based on land indicators, infrastructure, and equipment. The results of this study showed that most of the ports in the Persian Gulf region had a relative efficiency in the field of petroleum products. On the other hand, a significant difference was observed between the nominal capacity of acceptance of petroleum products of ports and the volume of oil product exchanges.

1. Introduction

The near- and off-shore industrial facilities and their fleets threaten the marine ecosystem's health in the coastal areas. The pollutions caused by operations of these facilities gradually spread off to beaches and islands leading to fatal diseases and irreversible genetic disorders on humans. Iran's economy heavily relies on the oil industry, particularly through the naval fleets in the Persian Gulf and the Oman Sea in the South and the Caspian Sea in the North where major oil extraction facilities and export ports are located. For example, there are 34 oil fields with more than 800 wells (Fig. 1) and about 20,000 to 30,000 tankers per year (Fig. 2) in the Persian Gulf [18]. Therefore, there is a high risk of environmental hazards caused by these operations [8]. About 100 to 160 thousand tons of oil and petroleum products are shipped in the Persian Gulf annually, and the rate of oil contamination in the region is 47 times higher than the world average [17].

On the other hand, rich oil and gas resources in the Caspian Sea have attracted a flood of foreign investors since the mid-1990s, thereby strengthening the energy development platform in the region. These developments increased extraction of oil, gas and other industrial products in petrochemical plants and oil refineries significantly which lead to the spread of pollution in the Caspian Sea region [15]. Severe contamination of carbonic acid and petroleum products resulting from oil extraction and the construction of oil pipelines has caused the contamination of about 30,000 hectares of the region and environment hazards [3] (Fig. 3). According to the Department of Energy's Energy Information Agency (EIA), the Caspian Sea region has oil reserves of more than 17 to 33 billion barrels and oil production in the region was around 2.1 million barrels per day in 2005 and up to 3.8 million barrels per day in 2010 [2].

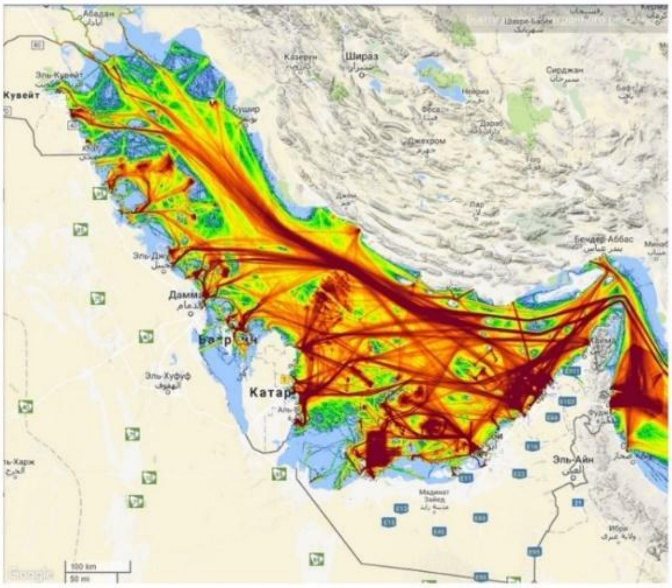

Fig. 1. Density map of ship traffic in the Persian Gulf in 2016, © marinetraffic.com

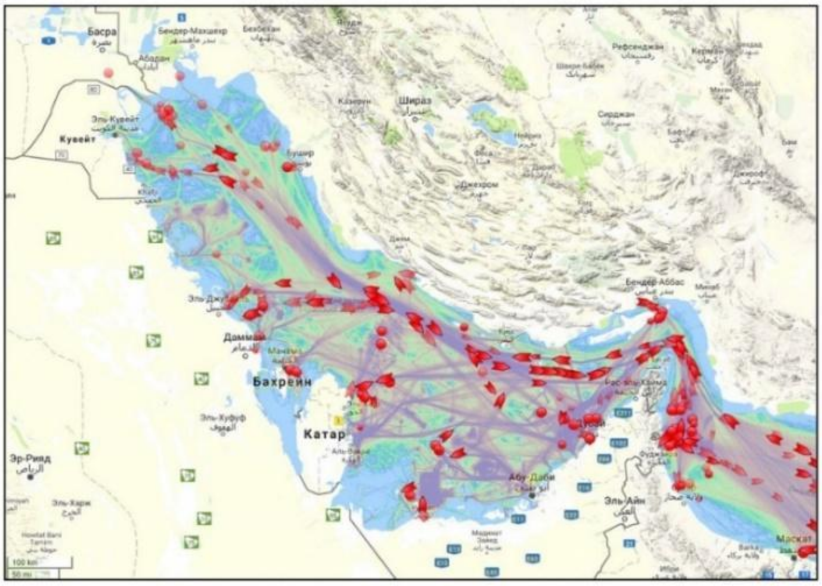

Fig. 2. The position of oil tankers in the Persian Gulf in 2018, © marinetraffic.com

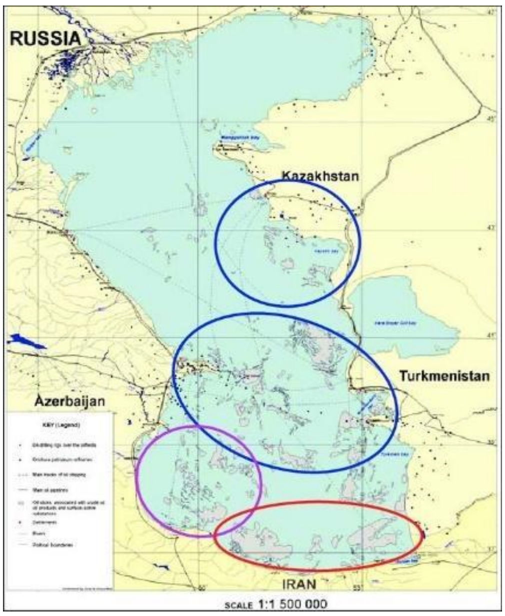

Fig. 3. Map of oil spills accumulation in the Caspian Sea areas related to crude oil in 1996, Ellipses show areas of oil slick accumulations over the oil production fields (blue), bottom seepages (violet) and river run-off (red), [10].

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Oil spills and contaminations mainly occur in the main and secondary routes of vessels, tankers operation zones, as well as in ports or berthing regions (Fig. 4). Therefore, prevention and reduction of marine environment hazards are critical in the ports' operation. For addressing these issues, the Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution was held in Kuwait in 1978 with the participation of Iran, Saudi Arabia, Bahrain, the United Arab Emirates, and Oman (Kuwait Convention).

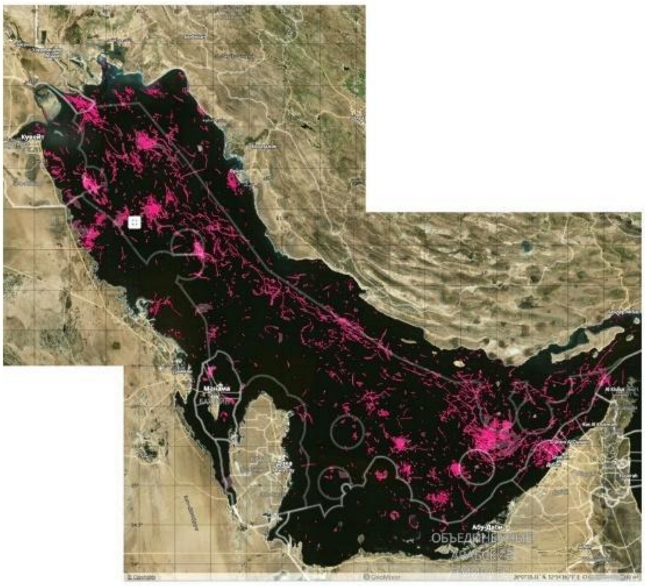


Fig. 4. Summary map of all oil spills detected in the Persian Gulf in 2017 on the Sentinel-1A and Sentinel-1B SAR images, © scanex.ru

Furthermore, due to the high operational cost of ports, the authorities should demonstrate to their investors and clients, their capabilities for the efficient operation of the equipment and traffic navigation.
Over the past decade, various models have been proposed to deal with efficiency such as Stochastic Frontier Analysis (SFA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Multiple-Criteria Decision Analysis (MCDA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy logic and Data Envelopment Analysis (DEA) which is based on weighted ratio of outputs to input and is useful for multi-criteria benchmarking studies. In this study, we evaluated and analyzed the efficiency in revenue generation of ports using Data Envelopment Analysis from two different modeling approaches; based on relating earnings to port operational capability and activity and based on land indicators, infrastructure, and equipment.

2. Data Envelopment Analysis Method

Data Envelopment Analysis (DEA) includes techniques and methods for assessing efficiency or measuring the productivity of decision-making units. The DEA is, in fact, the extension of Farrell's work in devising the first non-parametric method which measures productivity by considering a system of inputs and outputs. Using the inputs and outputs of the decision-making units and the principles governing them, Farrell [7] introduced a set called Production Possibility set and presented a part of its frontier as a production function. This frontier is also called the efficient frontier, and the decision-making units located on the frontier are considered efficient. But Farrell's method did not attract much attention until Charnes, Cooper, and Rhodes [5] established a method based on linear algebra.
The DEA offers many opportunities for collaboration between analysts and decision-makers. These collaborations can be efficient in selecting inputs and outputs of the units under evaluation, and functioning and modeling relative to the frontier. Efficiency means that each unit performs well under the influence of in-organizational indicators, expressed as the ratio of output to input (Fig. 5). In the case of multiple inputs and outputs for the decision-making unit, the ratio of the total weighted output to the total weighted input for the efficiency of that unit is measured [16].

$$Efficiency = \frac{\sum Output}{\sum Input} = \frac{u_1 y_1 + \cdots + u_s y_s}{v_1 x_1 + \cdots + v_m x_m}$$

The used notations can be described as follows:
x and y are the input and output vectors, respectively.
u_s output weight and v_m input weight.

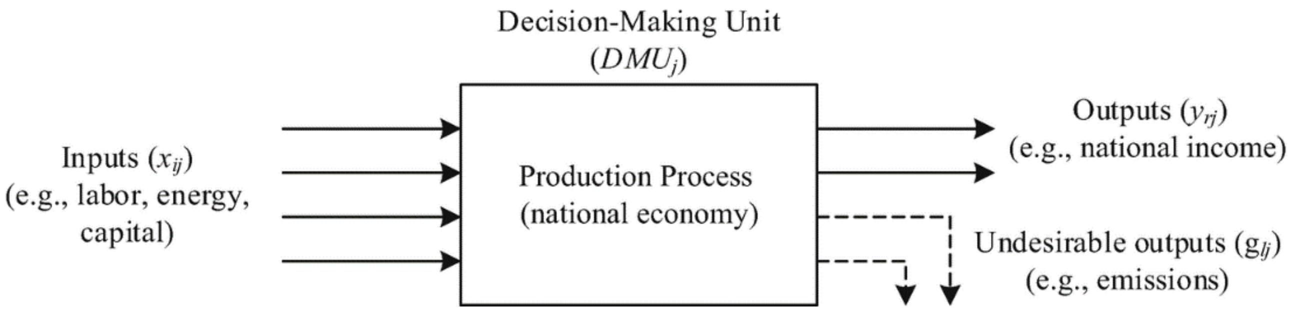


Fig. 5. The production process in a national economy, [9].

CCR (Charnes, Cooper and Rhodes) is the first DEA model to measure the efficiency of decision-making units presented by Charnes, Cooper and Rhodes in 1978. The number of data envelopment analysis models is increasing and is becoming more specialized [11]. But the basis of all DEA models are models with returns to the CCR constant scale and returns to the BCC (Bander, Charnes, Cooper) variable scale [13]. The DEA model can be divided in terms of being input- or output-oriented. Therefore, there are four general categories of DEA models:

- Constant returns to scale (CRS): Input-oriented & output-oriented
- Variable returns to scale (VRS): Input-oriented & output-oriented

In this study, the output-oriented CCR model is used to evaluate the efficiency of ports in terms of oil exchange and efficient units are ranked by AP method (Anderson, Peterson).

3. Output-Oriented CCR model

The name of this model is derived from the first letters of three scholars creating it, Charles, Copper and Rhodes. This model has a Constant Returns to Scale. Output-oriented models seek to increase or maximize outputs without increasing inputs or incremental resources. This model is shown in the following relation:

$$Max\ \varphi$$
$$\sum_{j=1}^{n} \gamma_j x_{ij} \leq x_{io}, i = 1, \dots, n$$
$$\sum_{j=1}^{n} \gamma_j y_{rj} \geq \varphi y_{ro}, r = 1, \dots, s$$
$$\gamma_j \geq 0, j = 1, \dots, m$$

The used notations can be described as follows:
φ: Efficiency of the under investigated DMU in period p, m: Index of DMUs, n: Index of inputs, s: Index of outputs, p: Index of time periods, x: ith input of the jth DMU in period p, y: rth output of the jth DMU in period p, γ: Benchmark for the jth inefficient DMU in period p.
Using this model of DEA to calculate efficiency and rank units, more than one unit may obtain the highest efficiency coefficient i.e. 1 and become efficient. In this case, it is not possible to compare and rank these units in relation to each other and the AP method can be used for ranking.

4. Results and Discussion

The Anderson-Peterson model or the super efficiency method was proposed by Anderson and Peterson [1] makes it possible to determine the most efficient unit to rank efficient units. In this method, the score of efficient units can be greater than 1 and thus the efficient units will be ranked just like inefficient units. The methodology is to remove the DMU from the production possibility set and apply the model to other DMUs. The larger the unit coefficient, the more efficient it will be. If the model is output-oriented, the goal is to drive an inefficient unit to the efficiency frontier by keeping the output constant and reducing input. The Min function type is used in this study.

$$Min\ \theta$$
$$\theta x_{ip} \geq \sum_{j=1, j\neq p}^{n} \gamma_j\ x_{ij}\ , i = 1 \dots n$$
$$y_{rp}\ \leq \sum_{j=1, j\neq p}^{n} \gamma_j x_{rj}\ , r = 1 \dots s$$
$$\gamma_j \geq 0, j = 1, \dots, m, j \neq p$$

The used notations can be described as follows:
θ: DEA efficiency, , m: Index of DMUs, n: Index of inputs, s: Index of outputs, p: Index of time periods, x: ith input of the jth DMU in period p, y: rth output of the jth DMU in period p, γ: Benchmark for the jth inefficient DMU in period p.

5. Literature Review

Chang [4] examined the efficiency of South Korean ports in terms of the environment. Using the Slacks Based Measure (SBM) and analysis of carbon dioxide data, he investigated the effect of reducing CO2 emissions on port efficiency.
Lee et al., [12], addressed the environmental efficiency of port cities affected by air pollution. By applying the SBM method and considering the Gross Regional Domestic Product (GRDP) as the model output, they investigated the role of air pollutants in the economic productivity of the port cities like Singapore, Busan, Rotterdam, Kaohsiung, Antwerp, and New York.
Cheon et al., [6] analyzed the relationship between environmental and economic efficiency of 10 important ports of the United States using data envelopment analysis and found a close link between environmental efficiency and port economic productivity.
Zahran et al., [19] analyzed the efficiency of port authorities in terms of monetization mechanism using two different modeling approaches, activity and infrastructure.
Grigoroudis and Petridis [9] used DEA method to estimate countries' environmental efficiency using slack-based model under the consideration of constant returns to scale and variable returns to scale method.
Mahmoudi and Emrouznejad [14] presented a literature review and classification of the applications of DEA in transportation systems by classifying 40 papers from 2007 to 2018. In this paper the origins of DEA in transportation problems have been reviewed and development of DEA applications have been presented.

6. Data and Variables

In this study, the efficiency of 12 ports in the Persian Gulf, Oman and Caspian seas (Fig. 6) from 2016 to 2018 are examined using DEA. Each of the ports is considered to be a decision-making unit that generates output by consuming inputs.

Fig. 6: Iranian ports, © pmo.ir

In this study, the most important and effective inputs and outputs for measuring the efficiency of oil ports are selected as shown in Table 1. A total of six input variables and one output variable is considered. The collected data shown in Tables 2-4 are gathered from the Ports and Maritime Organization of Ministry of Roads and Urban Development. It should be noted that the ports areas are modeled without considering the area of pack stations and roofed warehouses. It is noted that since the input and output indices of the model have different units the data is first descaled by dividing the values for each index by the sum of its values to obtain the weight ratio of each index.

Table 1. Input and output variables

Inputs	Outputs
Port and Hinterland Area (ha)	Import/Export of Petroleum Products (ton)
Number of Oil Jetties (posts)	
Total Length of Oil Jetties (m)	
Basin Depth (m)	
Capacity of Oil Jetties (ton)	
Number of Tugboats	

Table 2. Ports input and output data in 2016

Ports	Inputs						Outputs
	Area	**Jetties**	**Length**	**Depth**	**Capacity**	**Tugboats**	**Loading**
Abadan	6	1	136	5	5000	1	641
AmirAbad	1060	2	430	6	12000	5	41749
Anzali	132	1	183	5.5	5000	6	80231
Bushehr	27	1	250	11	25000	7	781680
Chabahar	270	1	265	14	80000	4	1055540
FereydunKenar	69	1	90	5	5000	1	38821
ImamKhomeini	1100	5	910	14	186000	11	18544165
Khorramshahr	182	1	30	5	1000	5	32
Lengeh	20	1	240	5.5	3000	1	1652
Qeshm	25	1	260	18	100000	2	100365
ShahidBahonar	15	2	335	10	10000	2	544346
ShahidRajaee	2400	9	520	12	150000	9	26116329
Total	**5306**	**26**	**3649**	**111**	**582000**	**54**	**47305551**

Table 3. Ports input and output data in 2017

Ports	Inputs						Outputs
	Area	**Jetties**	**Length**	**Depth**	**Capacity**	**Tugboats**	**Loading**
Abadan	7	1	136	5	5000	1	72
AmirAbad	1060	2	430	6	12000	5	38845
Anzali	132	1	183	5.5	5000	6	99498
Bushehr	27	1	250	11	25000	7	453435
Chabahar	270	1	265	14	80000	4	756811
FereydunKenar	69	1	90	5	5000	1	71705
ImamKhomeini	1100	5	910	14	186000	6	17771763
Khorramshahr	182	1	30	5	1000	4	120
Lengeh	20	1	240	5.5	3000	1	981
Qeshm	25	1	260	18	100000	2	108680
ShahidBahonar	16	2	335	10	10000	2	473783
ShahidRajaee	2400	9	520	12	150000	7	27139552
Total	**5308**	**26**	**3649**	**111**	**582000**	**46**	**46915245**

Table 4. Ports input and output data in 2018

Ports	Inputs						Outputs
	Area	**Jetties**	**Length**	**Depth**	**Capacity**	**Tugboats**	**Loading**
Abadan	7	1	136	5	5000	1	308
AmirAbad	1060	2	430	6	12000	5	26834
Anzali	132	1	183	5.5	5000	6	35113
Bushehr	27	1	250	11	25000	8	755899
Chabahar	270	1	265	14	80000	4	1098737
FereydunKenar	69	1	90	5	5000	1	29143
ImamKhomeini	1100	5	910	14	186000	6	16725342
Khorramshahr	230	1	30	5	1000	4	271
Lengeh	20	1	240	5.5	3000	1	811
Qeshm	25	1	260	18	100000	2	121577
ShahidBahonar	16	2	335	10	10000	2	461089
ShahidRajaee	3260	9	520	12	150000	12	25051546
Total	**6216**	**26**	**3649**	**111**	**582000**	**52**	**44306670**

Tables 5-7 provide a summary of descriptive statistics of variables. in this study. The average Port and Hinterland Area was 442 (ha) ranging between 6 and 2400 (ha). The average values of Basin Depth and Number of Oil Jetties (posts) were 9 (m) and 2 (Post), respectively. The ports Jetties handled 48500 vessel tons on average, whereas they have 4.5 tugboats. As for the output variable, the Import/Export of Petroleum Products was averaged at 3942129 (ton) with the maximum being 26116329 (ton) and minimum 32 (ton).

Table 5. Descriptive statistics of input and output variables in 2016

Variables	Units	Average	Maximum	Minimum	Standard Deviation
Port and Hinterland Area	Hectare	442.166	2400	6	730.982
Number of Oil Jetties	Post	2.166	9	1	2.443
Total Length of Oil Jetties	Meter	304.083	910	30	234.508
Basin Depth	Meter	9.25	18	5	4.530
Capacity of Oil Jetties	Ton	48500	186000	1000	64823.536
Number of Tugboats	Vessels	4.5	11	1	3.3166
Import/Export of Oil	Ton	3942129.25	26116329	32	8746455.71

Table 6. Descriptive statistics of input and output variables in 2017

Variables	Units	Average	Maximum	Minimum	Standard Deviation
Port and Hinterland Area	Hectare	442.333	2400	7	730.875
Number of Oil Jetties	Post	2.166	9	1	2.443
Total Length of Oil Jetties	Meter	304.083	910	30	234.508
Basin Depth	Meter	9.25	18	5	4.530
Capacity of Oil Jetties	Ton	48500	186000	1000	64823.536
Number of Tugboats	Vessels	3.833	7	1	2.367
Import/Export of Oil	Ton	3909603.75	27139552	72	8893317.32

Table 7. Descriptive statistics of input and output variables in 2018

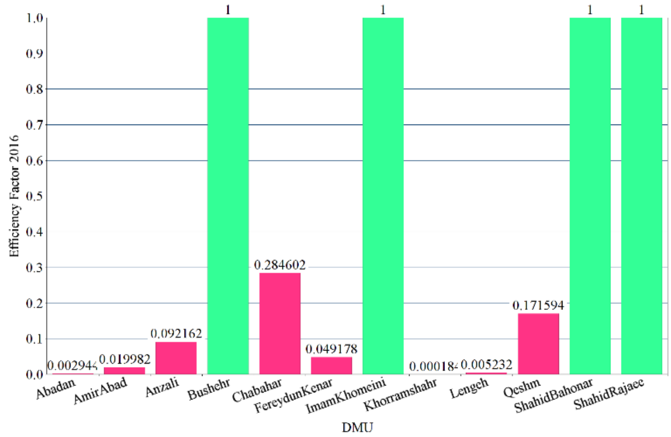
Variables	Units	Average	Maximum	Minimum	Standard Deviation
Port and Hinterland Area	Hectare	518	3260	7	948.269
Number of Oil Jetties	Post	2.166	9	1	2.443
Total Length of Oil Jetties	Meter	304.083	910	30	234.508
Basin Depth	Meter	9.25	18	5	4.530
Capacity of Oil Jetties	Ton	48500	186000	1000	64823.536
Number of Tugboats	Vessels	4.333	12	1	3.339
Import/Export of Oil	Ton	3692222.5	25051546	271	8233720.75

7. Model Implementation

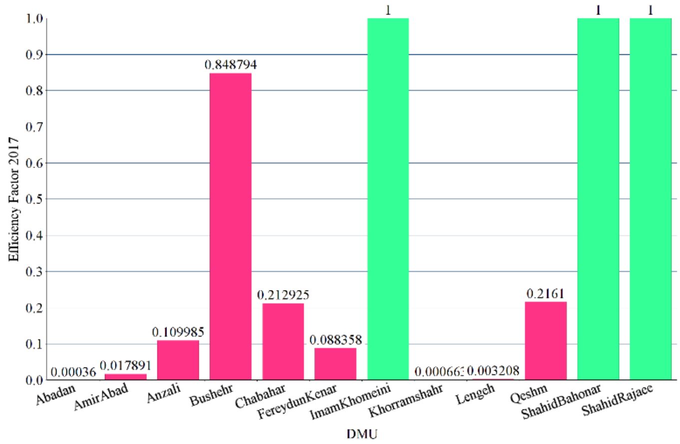
The Open Source DEA Project (© opensourcedea.org) is used to solve the data envelopment analysis model. As mentioned earlier, the Output-Oriented, Technical Efficiency and Constant Returns to Scale (RTS) method is used in this study (CCR_O). Technical Efficiency can be eliminated without changing the proportions between inputs and outputs. But Mix Efficiency can only be omitted by changing the proportion between inputs and outputs.

This DEA model attributes a virtual weight to each of input and output. Then the DMU performance is calculated using a linear optimization process which maximize each ratio by finding the best set of weight. The optimization process is imposed by existing data so that each dataset is compared against the best observed efficiency. The ports productivity assessment results for each year are shown in Table 8.

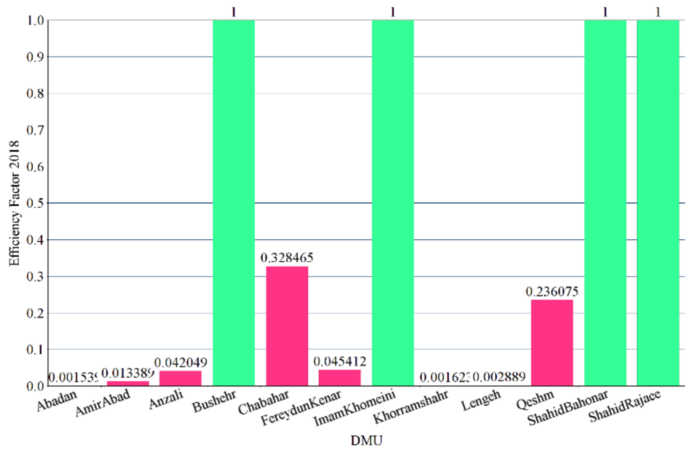
Table 8. Port Efficiency Factor



DMU Names	Objective Value	Efficient
Abadan	0.003	
AmirAbad	0.02	
Anzali	0.092	
Bushehr	1	Yes
Chabahar	0.285	
FereydunKenar	0.049	
ImamKhomeini	1	Yes
Khorramshahr	0.0	
Lengeh	0.005	
Qeshm	0.172	
ShahidBahonar	1	Yes
ShahidRajaee	1	Yes



DMU Names	Objective Value	Efficient
Abadan	0.0	
AmirAbad	0.018	
Anzali	0.11	
Bushehr	0.849	
Chabahar	0.213	
FereydunKenar	0.088	
ImamKhomeini	1	Yes
Khorramshahr	0.001	
Lengeh	0.003	
Qeshm	0.216	
ShahidBahonar	1	Yes
ShahidRajaee	1	Yes



DMU Names	Objective Value	Efficient
Abadan	0.002	
AmirAbad	0.013	
Anzali	0.042	
Bushehr	1	Yes
Chabahar	0.328	
FereydunKenar	0.045	
ImamKhomeini	1	Yes
Khorramshahr	0.002	
Lengeh	0.003	
Qeshm	0.236	
ShahidBahonar	1	Yes
ShahidRajaee	1	Yes

The Table 8 yields the following conclusions:
During 2016, 2017, and 2018, four Shahid Rajaee, Imam Khomeini, Shahid Bahonar and Bushehr ports had relatively better use of their resources than the rest, thus achieving better results and considered to be efficient (as shown by the green bars in Table 8).
Also, according to the super efficiency method, Shahid Rajaee and Imam Khomeini were identified as the most efficient ports, respectively.
On the other hand, Abadan inefficient port has had the least efficiency in 2016. In addition, Khorramshahr's inefficient port has been improved over these 3 years. On the contrary, Lengeh's inefficient port had a declining trend over the study period and had become more inefficient (as shown by the red bars in Table 8).

8. Conclusion

In this paper, the port productivity as a unit has been analyzed by comparing the amount of output produced in comparison to the amount of input using Data Envelopment Analysis from two different points of view; based on relating earnings to port operational capability and activity and based on land indicators, infrastructures, and equipment.
The proposed method to evaluate the performance can rank the ports with the same efficiency. The results of

this study showed that most of the ports in the Persian Gulf region had a relative efficiency in the field of petroleum products. On the other hand, a significant difference could be seen between the nominal capacity of acceptance of petroleum products of ports and the volume of oil product exchanges over the study period which could be attributed to the lack of competitive environment due to oil sanctions imposed on Iran's petrochemical industry.
On the other hand, the efficiency of the ports reflected the proper use and adherence of the country's maritime organizations to guidelines and conventions under the supervision of the International Maritime Organization (IMO) and the conduct of practical programs and regional maneuvers, as well as planning for dealing with contingency and emergency cases.
Subsequent studies can use more parameters as inputs and outputs to handle different combinations of evaluation factors, such as Proficiency of Operators and Personnel, Port Navigation Safety Information, Vessel Traffic Service (VTS), Hydrographic Surveys equipment and Nautical Charts, Port Accident Risk Assessment and so on.

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