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RESEARCH ARTICLE

Port efficiency evaluation of Turkish container ports based on DEA-SCOR model: An effective sea gateways in Türkiye for one belt and one road initiative

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ABSTRACT

This study aims to investigate the relative operational efficiency of major Turkish container ports based on the Data Envelopment Analysis - Supply Chain Operations Reference (DEA-SCOR) model. While Turkish export and import figures are growing, the scientifical studies on operational efficiency of Turkish ports are gaining more attention day by day. Of course, one of the important import countries is China for Türkiye and BRI (One Belt and One Road Initiative) tends to support Turkish trade between western and eastern countries. Therefore, Turkish ports' efficiencies should be identified and suggestions have been presented for further development. The sampling frame was chosen from the members of TURKLIM and therefore, the SCOR and Data Envelopment Methodology examined 23 seaports. Both methodologies are generally used for analyzing the operational efficiency of ship inward-outward and stackings. The findings of the study show that four major ports are the most efficient gateways to handle inward and outward container traffic with their input variables. However, there are some challenges in port investment for BRI. This study should be used for the further analysis in the sector reports and scientific papers.

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Introduction

The maritime sector is more important to the economic survival of many developing countries. That notwithstanding, problems to seaports administration have created circumstances of excessive delays to import and export cargoes, human and vehicle congestion in and out ports, and inadequate superstructures or infrastructures leading to huge costs of port operations. To improve the predictability, consistency of port operations led to the better transformation of the port services. Besides, multinational and mutual trade agreements help regional trade and investment and directly benefit ports. China launched at the BRI, which covers many countries. However, Türkiye cannot fully benefit from China's BRI investments. This project creates a great business potential for China and Türkiye.

Great transportation networks demand fast and efficient infrastructures. Container port offers a service but it is not a production line. This service provides a link between different transportation modes. A role of container port is to be soft converter between these modes. It is actually a buffer. BRI recommends connecting common seaports along the Belt and Road so that stable, strong, and effective transport routes could be mutually built (NDRC, 2015)**Hata! Başvuru kaynağı bulunamadı.**. By connecting common seaports along the Belt and Road, the idea is to create stable, strong, and effective transport routes that can benefit participating countries by increasing trade and economic integration. Turkish ports may be the buffers ports to support the BRI supply chain. On the other hand, this study measures the efficiency of Turkish container ports over a wide period of time. In similar studies (Aynur & Yanginlar, 2017; Akdamar & Eren, 2021; Huang et al., 2021), port efficiency was measured in a single time interval, making it difficult to see the efficiency trend between different times. In this respect, the study is more original than the others.

Therefore, it proves that port efficiency is very important for building strategic strength for hinterland development, improving trade and investment facilitations, and supporting major public prosperity and developments. This study aims to investigate the relative operational efficiency of major Turkish container ports based on the DEA-SCOR model. With regard to the aim, the study also analyzes the Turkish port efficiency in their geographical region.

This study consists of four sections including literature review, methodology, findings and conclusion. In the methodology section, DEA-SCOR model explained in detail and all score values presented in the section of findings. Finally, recapitulation of the study has been presented.

Literature Review

This section consists of two sections including port efficiency studies for container ports and BRI with Turkish port industry scope. Both sections discuss the literature in terms of port efficiency within the scope of BRI.

Port Efficiency Studies for Container Industry

The common method for assessing the efficiency of seaports is categorized into two approaches: the parametric and the non-parametric. The parametric methods measure the efficiency through the measurement of a theoretical production. The deviation from the function line is associated partially to the deficiency of efficiency and partially to the presence of measurement error (Cullinane et al., 2006). The stochastic frontier analysis (SFA) is the most important parametric method, which is initially studied for the port industry by (Liu, 1995). Aynur & Yanginlar (2017) measured the operational efficiency of Turkish container ports by using Technique for Order Preference by Similarity (TOPSIS) methodology. They used various criteria including terminal area, annual container throughput, terminal capacity of handling, number of containers, number of quays, quay length, and maximum draft. Various scholars (Coto-Millan et al., 2000; Cullinane & Song, 2003; Tongzon, 2001; Yan et al., 2009) were studied the evaluation of efficiency of ports and terminals. Sağlam & Açık (2020) measured the efficiency scores of Turkish container ports by recursive and cluster methods. The non-parametric methods measure the efficiency without the adoption of a certain production function based on the empirical data. The widely preferred non-parametric method is data envelopment analysis (DEA) (Cullinane & Song, 2006; Wu & Goh, 2010). DEA comprises a data analysis approach focusing at the benchmark of technical efficiency of decision-making unit (DMU). DEA is a linear programming method which benefits from the inputs and outputs of production process. The elements of the input include labor, land, equipment, that is, production related elements and the elements of the output include sales volume, production numbers or cargo throughput. The first study to perform DEA test in the port sector was done by (Roll & Hayuth, 1993) and this study was used a hypothetical sample of 20 ports where the methodology was applied using the CCR model. DEA methodology offers advantages to consolidate different methodologies such as, CCR, SCOR and BCC. Chen et al. (2019) tested the efficiency of the container port by using DEA-SCOR based model because, this model offers multiple input-output analysis in accordance with the components of port operation and service production, thereby likely to assess the whole performance of the ports (Wang et al., 2003). Therefore, this study performs the DEA-SCOR methodology to analyses the efficiency of container port. The SCOR model could ensure organizations from a variety of sectors with supply chain performance and relevant operations within companies, as well as comparison with other companies (SCOR Version 10.0, 2010). SCOR could describe and waive excessive and bad experiences in terms of supply chain; this situation has been seen in many industries, such as manufacturing (Hwang et al., 2008; Pottash et al., 2010; Li et al., 2011; Zhou et al., 2011; Hwang et al., 2014) construction (Cheng et al., 2010; Pan et al., 2010; Thunberg & Persson, 2014; Wibowo & Sholeh, 2016), service (Ellram et al., 2004; Yilmaz & Bititci, 2006; Sundarakani et al., 2018) and port (Wang, 2017; Wang & Du, 2019; Yan, 2019).

One Belt and One Road (BRI) Initiative and Turkish Port Industry within its Scope

The "One Belt One Road" project or initiative that China has been trying to develop in recent years for maritime transport and very important development for Turkish transportation infrastructure. The BRI has contributed to the development of infrastructure projects in Türkiye, such as the construction of the Istanbul-Ankara high-speed railway and the Trans-Anatolian Natural Gas Pipeline (TANAP). Additionally, the BRI has also created new trade and investment opportunities for Türkiye, and has strengthened economic ties between Türkiye and China. This initiative aims to create new trade routes, lines and job opportunities in order to better and more effective connection between China and Europe alongside with Transition Economies via 5 major routes. The application of the initiative started in 2015 but the project will be possible in the long term including all targeted countries. Countries covered by BRI; 52 African countries, Belarus, Bangladesh, Europe, Fiji, Georgia, India, Indonesia, Kyrgyzstan, Kazakhstan, Latvia, Malaysia, Myanmar, Pakistan, Sri Lanka, Russian Federation, Thailand, Tajikistan, Turkmenistan, Uzbekistan, Vietnam, Central and South America (Sismanyazici, 2017).

With regard to port industry and its relatedness with BRI, The Maritime Silk Road ends in the Shanghai, Shenzhen and Hong Kong, the three largest ports of China. The project begins from China's largest ports and uses canals and waterways. The two most important canals and waterways between the ports of Piraeus and China are the Suez Canal and the Strait of Malacca. The most important port in the Strait of Malacca is the state-owned Singapore port, the world's second largest container terminal. China's share and control of the container terminal in this port is very limited to a small stake. Another important port is Port Klang in Malaysia. In the MALAY Peninsula, China will spend 2 million USD to restore and develop the Kauntan port. China needs lots of raw material for its economy and cheapest logistics plays vital role to ship them into Chinese economy and ship them back to the western countries. It will provide a good opportunity to market their high value-added products to market. In this way, China wanted to add the global value chain to the already existing global supply chain (Esmer, 2016). Chinese companies played an active role in the deepening of Suez. Chinese construction company "CHEC" will build a new container terminal at the port of Ashdod (Sismanyazi, 2017). Again, an agreement was made with the Israeli authorities for the construction of a railway with Israel. Therefore, the initiative is so important for Mediterranean region to support economic development and maritime industry.

For Turkish port industry, the number and capacity of container ports have increased significantly as a result of privatization through the transfer of operating rights and the investments made by the foreign capital thanks to the facilities provided for port investments. They are in well condition in terms of capacity and number and also in terms of ship acceptance facilities, container handling capacities. Some of them are "one stop shop" ports, some of them are 4th generation ports with their logistics infrastructure, port inland connection and coordination with other transportation modes. By the way, China would like to reach the countries on the Black Sea coast, and the Chinese ocean carrier China Shipping (merged with Cosco), which operates increasingly larger Container ships, have chosen Kumport as the most suitable place to enter the Black Sea. Therefore, Türkiye's strategic location at the crossroads of Europe and Asia makes it a natural hub for transportation and trade between the participating countries of the BRI. Türkiye's ongoing infrastructure development projects, such as the construction of the Istanbul Canal, are expected to improve the country's logistics capabilities and further enhance its role in the BRI. However, the chances of getting more demand in Turkish ports also depends on the economic situation and trade dynamics between China and other countries within the BRI, as well as the effectiveness of Turkish ports to attract more trade and investment.

Methodology

The study has performed the data envelopment analysis (DEA) for measuring the efficiency of Turkish container ports. These seaports are the members of Port Operators Association of Türkiye (TURKLIM) and are operated by major terminal operators. The dataset was taken from the secondary data sources including website of TURKLIM, Turkish Transportation and Infrastructure Ministry and Turkish Port's Web Sites. The data (i.e., total container throughput) belongs to the years of 2018, 2019, 2020 and 2021. The total number of ports is 23, and both models have been explained in details.

SCOR Model

In 1990's, there is a need to measure the efficiency of supply chain and Supply Chain Council found a model named "SCOR". Today, this model is widely used for different researches and continuously updated to version 12.0. It is a categorized process model to develop strategies for process and performance management. It gives useful toolkit to scholars for defining the supply chain configuration. Although traditional supply chain consists of manufacturing process, the port industry does not involve manufacturing and include the business practices in the port industry. It includes five phases: (1) customer demand configuration, (2) port collection, (3) port service, including cargo collection, port handling, port commerce, distribution and warehousing and relevant logistics, (4) water transport to the downstream port and (5) terminal delivery (Wang, 2017). In this study, port collection and port service are very critical as per port internal operational efficiency. Huang et al. (2021) describe the process of SCOR in the port and define the variables and Decision Making Unit (DMU's) of DEA-SCOR based model. Workforce, usage of land and equipment is so critical for container ports (Dowd & Leschine, 1990). These variables can measure the efficiency but it is difficult to reach the cost of data for these type of variables from secondary resources. Huang et al. (2021) advised to use incorporate input variables including quay length, the number of container berths and fixed or mobile gantry cranes. Annual container throughput is approximately related to cargo-related facilities and services, it was considered as an output variable by all prior studies (Thunberg & Persson, 2014). Therefore, annual container cargo throughput is the output variable in this study. All definitions have been in detail in Table 1.

Data Envelope Analysis (DEA)

DEA-based models mostly were mostly inherited from DEA-CCR and DEA-BCC. (Cullinane et al., 2006). The CCR model is used to predict the overall technical efficiency (TE) estimating that returns to scale are constant although the BCC model with the estimation of variable returns to scale is used to predict the pure TE of a decision-making unit (DMU) at a given scale operation. Both models are used in the research since returns to scale of production function of the sample seaports is changeable without exact information. In this method, model orientation can be categorized into input- and output-oriented, which concentrates on minimization for inputs and maximization of output variables (Banker et al., 1984; Banker et al., 2004). For analyzing the port efficiency, this paper can adequately argue that sets of K linear programming envelopment challenges can identify an output-oriented efficiency problem in calculation, with different constraints between CCR and BCC models (Cullinane et al., 2006).

Table 1. The definitions of DMU, output and input variables

DMU, Output/Input(s)	Variables	Definitions
DMU	Ports (N = 23)	Decision Making Unit
Output	Total Container throughput	It represents the movement of a containerized cargo from the ship to an inland carrier or from an inland carrier to the ship, annually.
Inputs	Container Berth	Number of container berth for potential use by container ships primarily loading or discharging of cargoes.
	Wharf Length	It is length of port infrastructure on shore of a harbor.
	Number of Ship-to-Shore (STS) Crane	The number of large dockside crane found at container terminals for loading and discharging intermodal containers.
	Number of MHC Crane	The number of versatile port cranes, suitable for handling containerized cargoes.

Table 2. Summary statistics of sampling

No	Ports (DMU)	2018					2019					2020					2021				
		Input				Output	Input				Output	Input				Output	Input				Output
		Container Berth (piece)	Wharf Length (mtr.)	Number of STS cranes	Number of MHC cranes	Total Container throughput	Container Berth (piece)	Wharf Length (mtr.)	Number of STS cranes	Number of MHC cranes	Total Container throughput	Container Berth (piece)	Wharf Length (mtr.)	Number of STS cranes	Number of MHC cranes	Total Container throughput	Container Berth (piece)	Wharf Length (mtr.)	Number of STS cranes	Number of MHC cranes	Total Container throughput
1	Mersin International Port	21	3370	11	4	1722711	21	3370	12	5	1939029	21	3370	12	5	2009724	21	3370	12	5	2097349
2	Asyaport	4	2010	14	2	1117749	4	2010	14	0	1353409	4	2010	14	0	1437921	4	2010	14	0	1802517
3	Marport	7	2005	10	5	1573600	7	2005	10	5	1679340	7	2005	10	5	1557391	7	2005	10	5	1503254
4	Kumport	4	2174	7	6	1258294	4	2226	9	6	1281850	5	2226	9	6	1210780	5	2226	9	6	1211515
5	Gemport	12	2024	4	6	524652	13	2040	4	7	547190	13	2040	4	6	570427	2	2050	8	6	682064
6	DP World Yarımca	2	922	6	0	575869	2	922	6	0	616749	2	922	8	0	676731	2	922	8	0	666174
7	Evyap Port	6	1270	4	5	464756	6	1270	4	5	499908	6	1270	4	5	509757	6	1270	4	5	599566
8	Yılport Gebze	4	1455	8	0	551726	4	1455	8	0	564531	6	1455	8	0	524065	6	1455	8	0	566447
9	Nemport	6	1080	2	5	390071	6	1080	2	5	430014	6	1080	2	5	484371	6	1080	2	5	544568
10	TCDD Alsancak	4	650	5	3	610908	4	650	5	3	541679	4	650	5	3	531687	4	650	5	3	529131
11	Ege Gübre Aliağa	2	784	2	3	298045	2	784	2	3	380790	2	784	2	3	460297	2	784	3	2	488507
12	Limak İskenderun	8	920	2	5	317.961	8	920	2	5	388328	8	920	4	3	478614	8	920	4	3	476627
13	Socar Aliağa	2	700	3	0	277000	2	850	3	0	311162	2	850	3	0	307250	2	850	3	0	357314
14	Mardaş	3	905	0	9	351849	3	877	0	9	139580	3	877	0	9	114069	3	1073	0	9	222640
15	Assan Port	4	680	0	4	225496	4	680	0	4	248594	4	680	0	4	244643	2	680	0	2	214484
16	Borusan	5	1738	3	9	245499	5	1773	3	8	206395	5	1773	3	8	176117	5	1773	3	8	138491
17	QTerminals Antalya	2	1317	0	6	186290	2	1117	0	6	148750	2	1117	0	6	123983	2	1117	0	6	116786
18	Samsun Ceyport	3	1073	0	9	74129	3	1073	0	9	87840	5	776	1	4	97998	3	1073	0	9	102155
19	Roda Port	3	1200	0	5	86464	3	1200	0	5	99668	3	1200	0	5	82226	3	1200	0	5	92408
20	TCDD Haydarpaşa	4	3413	3	1	56067	4	3413	3	1	45565	4	3413	3	1	41586	4	3413	3	1	27221
21	Limaş	2	405	0	2	16311	2	405	0	2	17914	2	405	0	2	17687	2	405	0	2	25812
22	Akçansa Ambarlı	2	930	0	2	10530	2	930	0	2	26512	2	930	0	2	12522	2	930	0	2	16776
23	Bandırma Çelebi	5	2974	0	3	35695	5	2974	0	3	18581	5	2974	0	3	13340	5	2974	0	3	6981

Note: Source: Input values were collected from TURKLIM Sector Reports (2019, 2020, 2021, and 2022); output values were collected from various information sources, including TURKLIM sector report (2022). Each port is the decision-making unit, which is ranked by total container throughput according to the year of 2021.

The scale efficiency (SE) for the DMU can be calculated by the technical efficiencies derived from the CCR model (TE) and BCC model (PTE), regarding the formula SE (scale efficiency) = TE (technical efficiency)/PTE (pure technical efficiency). Additionally, Lee (2009) commented that the BCC estimates "variable returns to scale", i.e., the scale of output differing. The efficiency value measured in CCR is the "overall technical efficiency", considering that the efficiency value computed by BCC is "pure technical efficiency". If the calculated value is less than "1", this means inefficiency for the decision-making unit (Baran & Górecka, 2015). It may originate from misallocation of inputs, not the factors concerning operational scale.

For this reason, SE means the degree of DMUs' efficiency regarding the optimization of the maximum usage of inputs (Baran & Górecka, 2015). CCR model has been developed by (Charnes et al., 1978) and separated into input-oriented and output-oriented under constant return to scale (CSR). The model has following Eq. 1;

$$Maxh_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \quad (1)$$

Subject to;

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \; j = 1, \dots, n \quad (1.1)$$

$$u_r, v_i \geq; r = 1, \dots s; i = 1, \dots m \quad (1.2)$$

Each parameter is identified as follows:

(1) m: input (container berth, wharf length, number of STS crane, and number of MHC crane),

(2) s: output (total container throughput),

(3) n: DMU (number of ports),

(4) y_{rj}: the r. amount of the output of the j,

(5) DMU_{xij}: the i. amount of the input of the j,

(6) DMU_{ur}: the weights of assigned to the output variable,

(7) v_j: the weights assigned to the input variable.

With regard to parameters, the objective function is the rate of the weighted sum of the inputs to the weighted sum of the outputs. The DMU (ports) selects the weights that will make a maximization of the objective function. Constraints provide all weights (u_r and v_i) as a positive or zero, and the objective function takes the value between 0 and 1.

$$Maxz = \sum_{r=1}^{s} \mu_r y_{r0} \quad (2)$$

Subject to;

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad (2.1)$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \quad (2.2)$$

$$\mu_r, v_i \geq 0 \quad (2.3)$$

Linear transformation is used in the model and this transformation is difficult to compare linear programming model, as shown in Eq. 2 (Cooper et al., 2011). A linear programming model in (Thunberg & Persson, 2014) is run n times to determine the efficiency scores of DMU's. The weights that will maximize the efficiency score are determined for each DMU. Once the efficiency score is 1, the DMU is efficient, and when it is lower than 1, it is inefficient (Murat, 2020). Besides, the structure of the output-oriented CCR model is defined as in Eq. 3 (Cooper et al., 2011).

$$Minq = \sum_{i=1}^{m} v_i x_{i0} \quad (3)$$

Subject to;

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} \geq 0 \quad (3.1)$$

$$\sum_{r=1}^{s} \mu_r y_{r0} = 1 \quad (3.2)$$

$$\mu_r, v_i \geq 0 \quad (3.3)$$

Meanwhile, Banker-Charnes-Cooper (BCC) model was developed by the Banker et al. (1984) and the model is divided into input and output-oriented under variable returns to scale (VRS). Apart from CCR, convexity constraint is added to the BCC model (Cooper et al., 2011). Therefore, input-oriented BCC model is created as in Eq. 4 (Banker et al., 1984).

$$Maxz = \sum_{r=1}^{s} u_r y_{r0} - u_0 \quad (4)$$

Subject to;

$$\sum_{r=1}^{s} u_r y_{r0} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \leq 0 \quad (4.1)$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \quad (4.2)$$

$$u_r, v_i \geq \in, u_0 \text{ free in sign} \quad (4.3)$$

From this point of view, the output-oriented BCC model is defined as in Eq. 5.

$$Minq = \sum_{i=1}^{m} v_i x_{i0} - v_0 \quad (5)$$

Subject to;

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} - v_0 \geq 0 \quad (5.1)$$

$$\sum_{r=1}^{s} \mu_r y_{r0} = 1 \quad (5.2)$$

$$\mu_r, v_i \geq \in, v_0 \text{ free in sign} \quad (5.3)$$

As a result, the following prerequisites are fitted for the study. Firstly, the number of variables is at least three times as much. Secondly, the correlation of variables within each cluster is less than 0.70 (Cooper et al., 2011). The study was used to analyze the dataset of the DMU (ports) with the MAXDEA software. This software is very easy to use and most powerful for Data Envelopment Analysis and it includes 15,000 DEA models with most complicated models and no limitations on testing of decision-making units.

In the following section, Table 2 ranks the input and output variables of all container ports in terms of total container throughput, respectively.

Findings: DEA-SCOR Based Model Results

After successfully data collection, the appropriate model (DEA-SCOR model) has been determined and in line with model, the efficiency scores of Turkish container ports were calculated from input and output variables. As the decision-making units (ports) have an effect on the input and output, the study has used both methods: CCR-oriented and BCC-oriented. These methods are called as the input oriented and they aim to maximize the inputs at least given output level. An efficiency performance can range from CCR-focused to BCC-focused methods in policy suggestions. Jaber et al. (2022) confirms that the performance of DMU is better in BCC models compared to CCR models. In this study, the values of TE were calculated with CCR-oriented method and the values of PTE were calculated with BCC-oriented method. With these models, the efficiency scores of container ports were determined and afterward, efficient and inefficient ports were separated. On the other hand, the study presents benchmark scores to be an efficient terminal for inefficient ports in Table 3. Ineffective ports should be referenced to increase their efficiencies as per their benchmarks. For example, the reference ports of Kumport are Assan port, Asya port and Marport. The score of proportionate movement (container berth) for Kumport is the value of -0,74, that is, the port has not enough berth to handle the inward and outward high dense container traffic.

Regarding TE, PTE and SE results, Mersin International Port, Asya Port, Assan Port, and Marport are the most efficient container terminals compared to the other container terminals. Meanwhile, the study also shows that Rodaport, Samsun Ceyport, Yılport Gebze, TCDD Haydarpaşa, Borusan, Bandirma Çelebi, Evyap Port, Mardaş, and Limak İskenderun are the inefficient in terms of TE, PTE and SE results. That is, they do not effectively handle their facilities when they accommodate a number of containers in the inward-outward process due the challenges said in the section of conclusion. Additionally, the SE results of such ports (i.e., Akçansa Ambarlı, Limaş, TCDD Ambarli, etc.) indicates that scale effects are constrains because they have handling problem in the volume of the inward and outward container traffic. In contrast to them, such ports (i.e., Mersin International Port, Asya Port, Assan and Marport) carried out their operational efficiency better on maximum usage of input to handle ship entries and departures.

Table 3. Benchmark scores for inefficient container ports

Ports (DMU)	Benchmark Scores (Lambda)	Benchmark Set
Kumport	0.297958	Assan Port
	0.308293	Asyaport
	0.393748	Marport
Evyap Port	0.062889	Asyaport
	0.430122	Ege Gübre Aliağa
	0.506989	Nemport

From 2018 to 2021 in terms of SE, such ports (i.e., Mersin International Port, Marport, Assanport, and Asyaport) keep their efficiencies stable although efficiencies of these ports including Kumport, TCDD Alsancak, QTerminals Antalya, DP World Yarımca, Ege Gübre get descending. Moreover, Nemport is the only port that has increased its operational efficiency in a four-year period.

The study also measured benchmark scores of inefficient ports so that they can improve themselves on the basis of indicators. The operational result of Turkish ports is given in Table 4 in which TE donates the CCR model technical efficiency, PTE is the BCC model pure technology efficiency, and SE represents scale efficiency.

In terms of findings in Table 4, there are several efficiency gaps that Turkish ports may face, which can include:

a) Limited capacity: Some Turkish ports may not have the necessary infrastructure and equipment to handle large vessels and high volumes of cargo, which can limit their ability to compete with other ports in the region.

Table 4. Efficiency of different ports in Turkish container ports

	Ports (DMU)	2018			2019			2020			2021		
		TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
1	Akçansa Ambarlı	0.0933941179	1.0000000000	0.0933941	0.2132955743	1.00000000	0.2132956	0.1023695753	1.000000000	0.1023696	0.078215624	1.0000000000	0.0782156
2	Assan Port	1.0000000000	1.0000000000	1.0000000	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	1.000000000	1.0000000000	1.0000000
3	Asyaport	0.9414552315	1.0000000000	0.9414552	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	1.000000000	1.0000000000	1.0000000
4	Bandırma Çelebi	0.2110606544	0.7284429253	0.2897422	0.0996591497	0.66666667	0.1494887	0.0727045804	0.666666667	0.1090569	0.021698588	0.6666666667	0.0325479
5	Borusan	0.2993116935	0.4261526739	0.7023579	0.2925987650	0.40000000	0.7314969	0.2165417617	0.400000000	0.5413544	0.170452219	0.4000000000	0.4261305
6	DP World Yarımca	1.0000000000	1.0000000000	1.0000000	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	0.805700152	1.0000000000	0.8057002
7	Ege Gübre Aliağa	0.7109174779	1.0000000000	0.7109175	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	0.978565509	1.0000000000	0.9785655
8	Evyap Port	0.5897086173	0.6567010379	0.8979864	0.5931322826	0.67300293	0.8813220	0.6333936152	0.645627668	0.9810509	0.779242829	0.7961973113	0.9787057
9	Gemport	0.5946940820	0.6075704132	0.9788068	0.5569485744	0.56355097	0.9882843	0.6101228647	0.613562642	0.9943938	0.756790643	1.0000000000	0.7567906
10	Kumport	1.0000000000	1.0000000000	1.0000000	1.0000000000	1.00000000	1.0000000	0.8918051198	0.963334821	0.9257478	0.853657033	0.9170655534	0.9308572
11	Limak İskenderun	0.6357251530	0.7084572074	0.8973374	0.7388227844	0.80866984	0.9136272	0.7156239417	0.825835301	0.8665456	0.740459613	0.8088751894	0.9154189
12	Limaş	0.1446677546	1.0000000000	0.1446678	0.1441225452	1.00000000	0.1441225	0.1445943681	1.000000000	0.1445944	0.202060138	1.0000000000	0.2020601
13	Mardaş	1.0000000000	1.0000000000	1.0000000	0.7049659705	0.87217365	0.8082863	0.6190418483	0.836414205	0.7401140	0.692017431	1.0000000000	0.6920174
14	Marport	1.0000000000	1.0000000000	1.0000000	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	1.000000000	1.0000000000	1.0000000
15	Mersin International Port	1.0000000000	1.0000000000	1.0000000	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	1.000000000	1.0000000000	1.0000000
16	Nemport	0.7223976191	0.7565621856	0.9548424	0.7362037925	0.77174953	0.9539414	0.8545883769	0.885621123	0.9649593	1.000000000	1.0000000000	1.0000000
17	Port Akdeniz	0.7941901213	1.0000000000	0.7941901	1.0000000000	1.00000000	1.0000000	1.0000000000	1.000000000	1.0000000	0.544497492	1.0000000000	0.5444975
18	Roda Port	0.3758797727	0.7005043045	0.5365845	0.5016710961	0.75163553	0.6674393	0.4461215432	0.740620760	0.6023617	0.287225776	0.6666666667	0.4308387
19	Samsun Ceyport	0.2106841287	0.6666666667	0.3160262	0.4302429929	0.69426582	0.6197093	0.2660821131	0.589267021	0.4515476	0.317521742	0.6666666667	0.4762826
20	Socar Aliağa	0.9620243493	1.0000000000	0.9620243	1.0000000000	1.00000000	1.0000000	0.9971572384	1.000000000	0.9971572	0.925076065	1.0000000000	0.9250761
21	TCDD Alsancak	1.0000000000	1.0000000000	1.0000000	0.9949571718	1.00000000	0.9949572	1.0000000000	1.000000000	1.0000000	0.907750585	1.0000000000	0.9077506
22	TCDD Haydarpaşa	0.1278942619	0.6666666667	0.1918414	0.1017399462	0.66666667	0.1526099	0.0910495323	0.666666667	0.1365743	0.054854050	0.6666666667	0.0822811
23	Yılport Gebze	0.7185566509	0.7197070456	0.9984016	0.6851527730	0.68592087	0.9988802	0.6378053801	0.683369860	0.9333238	0.549943357	0.6659729175	0.8257744

b) Limited investment in port infrastructure: Insufficient investment in port infrastructure could lead to a lack of modern equipment and facilities, resulting in lower productivity and competitiveness.

On the other hand, Turkish ports are actively working on improving their efficiency, and many of the mentioned gaps are being addressed through modernization, investment and automation.

Conclusion and Limitations

This study is used DEA model to describe relative efficiency of ports, which is listed in the members of TURKLIM in the four-year period. An analysis has carried out using DEA – SCOR model. The initial findings involve the optimal efficiency of eight major ports and the tendency of the better port development in numerous ports. Although Turkish port industry may offer good efficiency to BRI, there are some challenges in front of the project. China does not make its game plan for BRI only for Türkiye, and even Türkiye's share is not very large in OBOR. Of course, there are investment plans in Türkiye for Chinese OBOR investments, but they have some challenges to struggle to manage the inward-outward container traffic for Turkish port industry.

Several Turkish ports have been identified as suitable for the Belt and Road Initiative (BRI) due to their strategic location and existing infrastructure. These include:

a) Mersin International Port (MIP) and Assan Port: Located on the Mediterranean coast, they are well-connected to major trade routes and has a large hinterland that includes the countries of the Middle East, Central Asia, and Eastern Europe.

b) Marport: It is the largest port in Istanbul, the largest city in Türkiye, and the main gateway between Asia and Europe.

c) TCDD Alsancak and Nemport: They are major commercial port on the Aegean coast with good connections to major trade routes in the Mediterranean and Europe.

d) Asya Port: It is a deep-water port located on the West Mediterranean coast that offers good connections to the Europe and Asia.

Mersin International Port (MIP) could be a suitable option for China as a sea gateway, as it is well-connected to major trade routes and has a large hinterland that includes countries of the Middle East, Central Asia, and Eastern Europe. Additionally, MIP has been developed as a hub port and has the capacity to handle large vessels and high volumes of cargo. However, it's worth noting that the final decision of which port to choose would be based on the specific needs and requirements of the initiative and the parties involved. The decision may vary according to such challenges. For example, Kumport is important sea gateway for BRI because Chinese companies (China Merchants Holdings International and China Investment Corporation) invested US$920 million to purchase a 65% stake at the Kumport Terminal in the region of Ambarli. As Turkish ports grow in scale and maturity, good cooperation with Chinese giants such as COSCO propose more hopeful collaborations. Although China selected the port of Kumport to reach Black Sea countries, the study shows that Kumport, located in Ambarli, should develop itself to handle the container throughput. However, there is no space to increase the capacity in Ambarli ports that are narrowed in the Istanbul city limits. The port practitioners in the region of Ambarli argue that expropriating the idle storage facility in Haramidere can solve this problem. Especially, container berth of Kumport should be expanded. Another problem is that private ports leased the coastal line from the National Real Estate for 49 years and when the privatization period is over, the state goes out to tender again. The leasing contracts on usage rights of the ports will be ended soon. Many private port operators hinder investments because the contracts will be ended after 49 years.

This study also offered benchmark scores for potential improvements, in other words, the sources of inefficiencies were determined. Each score on average, the greatest potential need for improvement was found in the container berth length (average 60%). That is, container ports achieve efficiency and greater handling capacity by increasing container berth length. In case of expansion of container berth, Turkish ports maybe more competitive as buffers ports for BRI. This is not only the 'efficiency requirement' but also it is an operational necessity. The buffers ports would allow to avoid congestion in the BRI supply chain.

There are certain limitations in this study. Such indexes including the infrastructure, capital, human sources, information and port technology, type of management was removed. Then, this study only focused on the SCOR based approach and different approaches might be combined with data envelopment analysis. Thus, the efficiency evaluation of container terminals is one-dimensional. For the further research, a low sample size will answer how to categorize Turkish container ports according to throughput capacity, and assess the efficiency of each grade of ports to obtain better results. On the other hand, there are several studies investigating efficiencies of Turkish container ports by recursive and cluster methods. Literature may be extended by including these studies in the future.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statements

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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