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Measuring the performance of container terminals using data envelopment analysis; A case study from Iskenderun Bay

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A B S T R A C T

In developing and growing economies, the greatest need is for raw materials. Additionally, facilitating the delivery of the materials which are used for production and those produced for consumption to end users is of great importance. Sea transport and container shipping are the most widely used methods in the execution of these activities. In this study, the aim is to determine to what extent the increasing international logistics needs in the container shipping sector can be met through the container terminals in the İskenderun Bay, and which measures has need to analyse to enhance the performance of these terminals. Data Envelopment Analysis (DEA) method was used to determine the relative efficiency of container terminals, which is a non-parametric method. The input values and output values of the decision units (container terminals) identified within the scope of the study for the last five years were obtained, and their efficiency during this period was examined. In the analysis, the input variables considered were quay length, container storage area, number of berth cranes, the amount of ship berths, the amount of container handling equipment, while the output variable was the handled container quantity. Efficiency measurements were obtained using Data Envelopment Analysis, CCR, BCC input and output-oriented results were obtained. A comparison of efficiency among the evaluated container terminals was made within the scope of the study, and recommendations were provided for the enhancement of inefficient decision-making units.

INTRODUCTION

Following the significant changes in the world economy after the 1970s due to globalization, the amount of imports and exports in international trade has shown a significant increase. Transportation plays an important role in the rising foreign trade activities. Transportation involves the process of moving people or goods from one place to another. Alternatively, it can be defined as the movement of goods and services from their place of production to their place of consumption through various transportation methods. Among the transportation systems used today, maritime transportation has the largest share. Approximately 80% of global trade and 90% of Türkiye's imports and exports are carried out by sea (Topaloğlu, 2007). Moreover, the level of development in maritime trade has averaged 3.1% over the past 30 years (UNCTAD, 2009). The advantages of sea transportation include its relative safety compared to other methods, speed and practicality considering the level of goods transported, and economic efficiency due to the ability to transport large quantities at once. These advantages are the main reasons why sea transportation is preferred over other types. As a result, the maritime industry has experienced high growth rates along with the growth of world trade.

Technological advancements in the maritime field have played a critical role in the rise of global trade. These can be explained as increases in ship capacity, developments in handling methods, and advances in information and communication technologies (Chlomodis and Pallis, 2002). These developments have facilitated transportation activities over long distances. To keep pace with the development in the global maritime sector and progress in proportion to these developments is a necessity for the continuation of the presence of countries and enterprises in maritime transportation.

Among the three main elements of maritime transportation-cargo, port, and ship-port efficiency can be considered the most influential on effectiveness/productivity. Initially defined as the place where the sea and land meet, ports were later seen as industrial and commercial centers, and today they serve as logistics bases. Ports have now become intermodal connection points in commercial competitions within the international supply chain (Esmer, 2010).

Ports can be defined as places where the mode of transportation changes. Despite being defined in many different ways in the literature, ports can be broadly described as open or closed areas and facilities providing physical spaces where ships can take refuge in adverse weather conditions, carry out loading-unloading operations, and embark and disembark passengers. They are established to provide infrastructure for these services, have the necessary units and organizations for inspection operations, are economically significant factors, serve as a transition mechanism between transportation methods, and enable the transfer between ship-to-ship, ship-to-land, and land-to-ship (Alkan and İncaz, 2003). In addition to being the fundamental element of maritime practices, ports contribute valuable benefits to the development of their location, the economy, and national defense. However, for ports' contributions to have a beneficial effect, efficient use and management of the port are necessary. The increase in port efficiency can be achieved not only by using technology but also by timely applying or developing new technologies.

In the maritime sector, point-to-point transportation has replaced port-to-port transportation, which was dominant until the 1960s. The system that enabled point-to-point transportation is container transportation. The increasing value of containerization has been an important factor in the development of ports (Beresford et al., 2004). Subsequently, technological changes in loading and unloading methods have strengthened the relationship between ports and their hinterlands. It can be said that the service area and infrastructure of ports have changed according to the requirements of international transportation (Teilet, 2006).

Terminals are specialized sections of ports for handling a specific type of cargo. Container terminals are places where cargo transfer is carried out between sea, land, and rail. In international container traffic, intermodal transportation, which is based on door-to-door transportation, is an essential mode. This mode of transportation involves a land or rail segment at both ends, in addition to the sea segment. Nowadays, ports tend to focus on a specific type of terminal. Therefore, ports generally operate through a single type of terminal. This enables ports to provide more reliable and faster services. The main goal of ports is to complete cargo handling in the healthiest and shortest way possible and to offer all other services to their customers without any issues. Thus, it is important to specialize in one or a few types of cargo (Bayar, 2005).

Container terminals are areas where container movements are carried out from land or rail to ship or vice versa, and container handling services are provided (Dowd and Leschine, 1990), Terminals play a crucial role in container transportation. They are connection points between sender and carrier systems. Terminals perform various functions to facilitate cargo movement. All transport modes use terminals. Terminals can be any point where mode changes, value-added activities, or both are performed, and where cargo is stopped or paused (UNCTAD, 2004). Containers arrive at the port by land or sea. They are handled by equipment on the port site and transferred to another ship, land, or rail. Container terminals are used to load and unload containers onto and from ships, temporarily store them, and deliver them from carrier to consignee or from sender to consignee (Ateş et al., 2010).

In today's container transportation by sea, there are three main routes. The most active and busiest of these routes, based on the preferences of regional operators and the development of container infrastructure in ports, is the Transpacific route (Kozanhan, 2008). Considering the Turkish maritime sector, the use of the Turkish Straits in maritime trade with countries bordering the Black Sea, Türkiye's geopolitical position in the Mediterranean, and its wide hinterland (Caucasus, Middle East, and Balkans) highlight Türkiye among many countries. The reasons for Türkiye lagging behind the world average in the maritime sector are attributed to the inability to effectively and efficiently use its geographical position and failure to adapt to developing technology.

Performance measurement in the port industry is done by evaluating changes in the port using multiple indicators (Ashar, 1997). Since ports are primary service providers for ships and cargo, it is evident that their performance cannot be evaluated with a single parameter. However, careful consideration should be given to which parameters to use in performance measurements using more indicators.

Data Envelopment Analysis (DEA) has been the most used method for port performance measurement in recent periods. DEA is a non-parametric method that allows comparison between enterprises using selected parameters and provides a way to compare the efficiencies of the enterprises being evaluated. Before conducting the analysis, it is necessary to know the details of the enterprises to be compared and ensure that the data to be evaluated is used for similar purposes. This method can be applied to many sectors such as insurance companies, agriculture, banks, schools, hospitals, fisheries, and ports. The efficiency analysis using DEA provides results based on the common input and output values used in the evaluation. Thus, it is relative. To accurately calculate efficiency in ports, it is essential to correctly determine the input and output units in the ports. Otherwise, the efficiency scores obtained from the port analysis may not be accurate (Ateş, 2010).

In the transportation sector, ports must evaluate their current status, identify underutilized resources, and take necessary measures to resolve inefficiencies to compete with other ports. Optimal use of resources is especially necessary in ports. In this context, the effectiveness of operations carried out at the port and the efficient use of resources are important. Developments in logistics have rapidly transformed both container transportation and port operations. These developments aim to ensure that the right product reaches the right place at the right time for the right price worldwide. As a result of this process, global logistics service providers have emerged over the past twenty years. The primary goal of these providers is to increase customer satisfaction. Reliable partnerships in the fields of distribution and transportation are crucial to achieving this goal (De Monie et al., 1998; Notteboom, 2004).

Iskenderun Bay has historically been an important trade center as a gateway for trade with Iran and India. Today, this region stands out with its ports in the Iskenderun Bay, which are the closest terminals to delivering expected increases in production in irrigation, agriculture, livestock, cold storage, packaging, food, and machinery industries to the Middle East and other countries. Factors such as the water issues in the Middle East, the Southeastern Anatolia Project, the Adana plains, the Adana-Yumurtalık free zone, the transfer of Azerbaijani and Caucasian oil to the Iskenderun Bay through pipelines, and the iron-steel industry increase the importance of the region today. It can be evaluated that the ports in the Iskenderun Bay and its surroundings have the widest hinterland both nationally and internationally in our country. Therefore, the facilities built and planned in the Iskenderun Bay, their economic positions, functions, external relations, and interactions with each other gain great importance (Alpar, 2001).

The aim of this study is to examine the efficiency level of container terminals in the Iskenderun Bay and to investigate the reasons affecting the efficiency of terminals that are not efficient.

MATERIALS AND METHODS

Study area

This study was conducted in the Iskenderun Bay, which, with an area of 2272 km², is located at the Northeastern Mediterranean Sea, the largest inland sea in the world (Figure 1). Iskenderun Bay is situated between 36° 19'–36° 55' N latitudes and 035° 33'–036° 12' E longitudes. Iskenderun Bay lies between the provinces of Adana and Hatay. The region is of high commercial importance in terms of sectors such as fishing, maritime logistics, tourism etc. (Can et al.,2020; Demirci et al., 2020; Demirhan et al., 2020; Akar et al., 2022; Yılmaz et al., 2022). Being developed in terms of both land and sea transportation, Iskenderun Bay is named after the Iskenderun district of Hatay. The Port of Iskenderun is the third largest port on the Mediterranean coast of Türkiye (Pachakis et al., 2013). Due to the attack on the Port of Beirut and the events in the Middle East, the Iskenderun Bay has gained more value and importance.

Figure 1. The location of the Iskenderun Bay within the Mediterranean

Within the boundaries of the Iskenderun Bay, there are two container ports: Limak Port located in the center of Iskenderun district and Assan Port located in the Sarıseki neighborhood of Iskenderun. Basic information about Limak and ASSAN container ports is provided below.

Assan Port

Assan Port is located at the easternmost tip of the Iskenderun Bay at 36°41′06″N, 36°11′40″E, in the Sarıseki neighborhood of Iskenderun district. Established in June 2010 by Assan Liman İşletmeleri A.Ş., a subsidiary of Kibar Group, in the Iskenderun Organized Industrial Zone, Assan Port has become one of the container terminals serving modern container ships within the Iskenderun Bay. Serving the same hinterland as Mersin, Assan Port Iskenderun operates as a second and very important alternative in the region. Assan Port continues its operations with the partnership of Terminal Investment Limited SA (TIL) since

2013. Assan Port's capacity is 250,000 TEU annually, and it provides services to "Container, General Cargo, Project Cargo, and Dry Bulk Cargo Ships" (Table 1). Geographically, Assan Port Iskenderun offers advantages to companies in the Eastern Mediterranean, Southeastern Anatolia, and the southern part of Central Anatolia; it is also the closest container terminal opening westward for Northern Syria and Iraq (Kibar, 2024).

Table 1. Assan Port Terminal Features (Kibar, 2024)

Port Characteristics	Specifications
Berthing Area	2 x 340 m
Depth	16 m - 19 m
Serviced Ship Types	Panamax, Post Panamax, Super Post Panamax, 350m LOA, 15.5 Draft
Capacity (Container)	250000 TEU/year
Capacity (General Cargo)	1700000 Tons/year
Duty-Free Zone - Total Area	47850 m²
Vehicle Parking Area	5000 m
Customs Zone - Pier Width	45 m
Customs Zone - Customs Area Outside Pier	80,434 m²
CFS Area	1600 m²
Closed Warehouse and Closed Area	1900 m²
Reefer Plug	288
IMCO Area	84 TEU

Limak Port

Limak Port is located at the southeastern tip of the Iskenderun Bay at 36°35′43″N, 36°11′22″E, in the Çay neighborhood of Iskenderun district. Historically significant, Limak Port (formerly known as Iskenderun TCDD Port) was transferred to Limak Port A.Ş. for 36 years on December 30, 2011, following the Privatization High Council's decision dated December 30, 2004, and numbered 2004/128. Following the transfer, Limak Port A. Ş. undertook extensive renovations to transform Iskenderun Port into a modern container port. Quay structures, storage areas, roads, port entrances and exits, warehouses, and all buildings were renovated or rebuilt, and the quay and terminal cranes were updated. Dredging operations enabled ships with a draft of up to 14.50 – 15.00 meters to berth. The port continues its operations under the name Limak Iskenderun International Port Management A.Ş. With a capacity of over 1 million TEU containers, LimakPort Iskenderun is one of the largest container ports in the Eastern Mediterranean region. Since its transfer to Limak Port A.Ş., container operations began in March 2013, and cargo volumes have significantly increased each year. LimakPort Iskenderun connects directly and via transshipment to many ports worldwide with mainline and feeder vessels (Limakport, 2024).

The port operates over an area of 1 million square meters, featuring long quay structures, a fully protective breakwater, and deep-water port characteristics. LimakPort, equipped with modern container handling equipment specifically designed for the port, including STS and RTG cranes, is container-focused. With comprehensive and multi-faceted investments, it has become the region's most important port for Ro-ro, Ro-pax, project cargo, bulk cargo, general cargo, and live animal cargo operations (Table 2).

Table 2. Limak Port Terminal Features (Limakport, 2024)

Port Characteristics	Specifications
Port Technical Features	1000000 m²
Port Area	8
Number of Quays	15.5 m
Container Quay Depth	732 m
General Cargo Quay Length	920 m
Container Quay Length	600
Reefer Plug	1000000 TEU / Year
Container Capacity	3247000 Tons / Year
Conventional Cargo Capacity (Bulk Cargo, General Cargo, Project Cargo)	120000 Vecihle / Year
Ro-Ro Capacity	30000 Truck / Year

Methodology

The purpose of this application is to calculate and compare the relative efficiency of container terminals operating in the Iskenderun Bay and to provide guidance for making inefficient terminals efficient by evaluating their performance. The goal is to optimize the use of existing resources at the terminals based on the findings obtained from the analysis. Additionally, efforts to improve container terminal efficiency and performance in the Iskenderun Bay will be examined.

In this study, the "Open Source DEA" software program was utilized to determine the efficiency levels of container terminals in the Iskenderun Bay. Data envelopment analysis was applied to container terminals in the Iskenderun Bay as part of the research. The method included a five-year period, and input-output changes were observed annually during this period.

Although the scope of this study involves analyzing the efficiency of container terminals operating in the Iskenderun Bay, due to the limitation of decision-making units [m+p+1=7 is required, but we only have 2 (Assan and Limak ports)], the efficiency evaluation will only cover Assan and Limak container terminals. Additionally, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport Port, Bandırma Çelebi Port, and Gemport Port container terminals, which are not located in the Iskenderun Bay but ensure homogeneous distribution in the analysis, closest container terminals to Iskenderun Bay operating in Türkiye were included. Statistical data for the years 2018, 2019, 2020, 2021, and 2022 were used, and the data envelopment analysis was conducted.

Statistical data for M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport Port, Bandırma Çelebi

Port, and Gemport Port container terminals were obtained from the annual sector reports of the Turkish Port Operators Association (TÜRKLİM) and the websites of these ports. These statistical data were used solely to yield effective results from the analysis. Since the comments are based on the research results, the evaluations are only valid for the ports included in the study's sample.

Data Envelopment Analysis

In data envelopment analysis models, the objective is to maximize or minimize a function with certain constraints. In linear programming, where the efficient use of resources is desired, it is assumed that all coefficients related to the model are known, there is proportionality in the function and constraints, outputs and inputs are independent of each other, the results do not need to be integers, and the variables are positive (Ünsal et al., 2000). To measure the performance of container terminals operating in the Iskenderun Bay, both input-oriented and output-oriented CCR (CRS – Constant Returns to Scale) and BCC (VRS-Variable Returns to Scale) models were applied using the input and output variables with the Open Source DEA program.

CCR Model

The CCR model was developed by Charnes, Cooper, and Rhodes in 1978. In the CCR model, the ratio of output to input is determined by weights. The CCR model, which is based on the assumption of constant returns to scale, can be either input-oriented or output-oriented. Models can be established to minimize inputs while providing the same output quantity. These types of models are called input-oriented models. Models aiming to maximize output using the same level of input are called output-oriented models (Zerey, 2010).

Input-Oriented CCR Model

The Input-Oriented CCR Model investigates how much the input quantity should be reduced without changing the output level. In the input-oriented CCR model:
h_j is the efficiency score,
$h_j = 1$ and if the residuals are zero, this decision-making unit is efficient.
$h_j < 1$ means this decision-making unit is inefficient.

Objective Function:

$$Enb\ h_j = \sum_{r=1}^{n} u_r\, y_r \tag{1}$$

Restrictions:

$$\sum_{i=1}^{m} v_i\ \ x_i = 1$$
$$\sum_{r=1}^{n} u_r\, y_r - \sum_{i=1}^{m} v_i\, x_i \ \leq 0$$
$$u_r, v_i\ \geq 0$$

In this formula, "hj" is the efficiency ratio of the j-th decision-making unit. The objective function in the model is to maximize the weighted average of the outputs. In the first equality, the weighted average of the inputs of the decision unit of interest is set equal to "1." Thus, the weighted average of the inputs is "1" for each decision unit. The constraint in the second equality ensures that the weighted average of the outputs is less than or equal to the weighted average of the inputs. Consequently, the OUTPUT / INPUT ratio can be at most "1" for each decision unit. For decision-making units that are inefficient, i.e., below the efficiency frontier, the weighted average of the outputs, or the efficiency ratio, will be less than "1" (Örkçü, 2004).

Output-Oriented CCR Model

The Output-Oriented CCR Model investigates how much the output quantity should be increased without changing the input quantity. The difference between the Output-Oriented CCR Model and the Input-Oriented CCR Model is that the ratio of weighted input to weighted output is minimized in the output-oriented model. In the output-oriented CCR model (Örkçü, 2004):

g_j is the efficiency score,
$g_j = 1$ and if the residuals are zero, this decision-making unit is efficient.
$g_j > 1$ means this decision-making unit is inefficient.

Objective Function:

$$Enb\ g_j = \sum_{i=1}^{m} v_i\, x_i \tag{2}$$

Restrictions:

$$\sum\nolimits_{r=1}^{n} u_r\ \ y_r = 1$$
$$-\sum\nolimits_{r=1}^{n} u_r\, y_r + \sum\nolimits_{i=1}^{m} v_i\, x_i\ \geq 0$$
$$u_r, v_i\ \geq 0$$

Here, g_j is the inefficiency ratio of the j-th decision-making unit.

BCC Model

The BCC model, is a technique developed by Banker, Charnes, and Cooper in 1984, and it is named after their initials. The fundamental difference between the BCC and CCR models is that the BCC model's Variable Returns to Scale (VRS) models are constrained by the intensity vector (λ), where the sum of the decision variables equals 1. This constraint removes the necessity for decision-making units in the CCR model to be scale-efficient. As a result, BCC models measure only technical efficiency for each decision-making unit under the VRS assumption. For a decision-making unit to be CCR efficient, it must be both technically and scale-efficient, whereas for it to be BCC efficient, it only needs to be technically efficient. Therefore, while the CCR model measures total efficiency under constant returns to scale, the BCC model measures technical efficiency under variable returns to scale (Bowlin, 1998).

Input-Oriented BCC Model

The input-oriented BCC model is the BCC model that investigates the minimum amount of input needed to achieve the same amount of output. In the input-oriented BCC model, θ^* is the efficiency score;

θ^* =1 and if the residuals are zero, this decision-making unit is efficient.
θ^* <1 means this decision-making unit is inefficient.

Objective Function:

$$Enk\ \theta_k \tag{3}$$

Restrictions:

$$\sum_{j=1}^{t} \lambda_{jk} = 1$$

$$\theta_k x_{rk} - \sum_{j=1}^{t} \lambda_{jk}\, x_{rj} \geq 0$$

$$\sum_{j=1}^{t} \lambda_{jk}\, y_{ij} \geq y_{ik}$$

$$\lambda_{jk} \geq 0$$

Here, θ_k is the efficiency ratio of the k-th decision-making unit (Erpolat, 2011).

Output-Oriented BCC Model

The output-oriented BCC model is the BCC model that investigates the maximum output level achievable using the same amount of input. In the output-oriented BCC model, ω_k is the efficiency score;

ω_k = 1 and if the residuals are zero, this decision-making unit is efficient.
ω_k > 1 means this decision-making unit is inefficient.

Objective Function:

$$Enb\ \omega_k \tag{4}$$

Restrictions:

$$\sum_{j=1}^{t} \gamma_{jk} = 1$$

$$\omega_k y_{ik} - \sum_{j=1}^{t} \gamma_{jk}\, y_{ij} \leq 0$$

$$\sum_{j=1}^{t} \gamma_{jk}\, x_{rj} \leq x_{rk}$$

$$\gamma_{jk} \geq 0$$

Here, ωk is the inefficiency ratio of the k-th decision-making unit (Erpolat, 2011).

RESULTS AND DISCUSSION

Variables affecting terminal efficiency in container terminals have been largely identified as a result of studies in the literature. Although there are various perspectives, the general view is that the input variables such as quay length, terminal area (storage area), and the number or capacity of cranes (mobile cranes or large port cranes) used for container handling are the most important factors affecting the efficiency of container terminals. If a single output variable is to be used, the amount of containers handled (TEU) can be used as the output variable (Notteboom, 2004; Ateş, 2010)

In this study, the efficiency of container terminals was calculated. Five input variables and one output variable, which are necessary for the topic, were utilized. These variables are quay length (m), number of cranes at the terminal (units), container storage area (m^2), number of berths (units), and number of container stacking vehicles (units) as input values. The amount of containers handled (TEU) was used as the output value.

Table 3. Quay lengths of container terminals

Port	2018	2019	2020	2021	2022
Assan Port	720	720	720	720	720
Limak Port	1170	1170	1170	1170	1170
MIP Port	3370	3370	3370	3370	3370
Q Terminals Antalya	1117	1117	1117	1117	1178
TCDD İzmir Alsancak	1414	1414	1414	1414	1414
Nemport	1080	1080	1080	1080	1689
Bandırma Çelebi	2973	2973	2973	2973	2973
Gemport	2040	2040	2040	2050	2050

It can be said that quay length is the most important input variable that can be used in measuring the efficiency of container terminals. A container quay is a structure that allows container ships to load and unload safely at ports using cargo handling systems, providing a connection between land and sea vehicles. Therefore, it is an important criterion when measuring efficiency. The data on the quay lengths of the container terminals included in the analysis are presented in Table 3.

Cranes

Cranes are the main equipment affecting the cargo handling capacity of container terminals. Therefore, they have been used as an input value in the study. The number of cranes examined includes the total of gantry cranes and mobile cranes used for container handling. The data on the number of container cranes at the container terminals included in the analysis are presented in Table 4.

Table 4. Number of container cranes

Port	2018	2019	2020	2021	2022
Assan Port	4	4	4	4	4
Limak Port	20	20	20	20	20
MIP Port	17	17	17	17	17
Q Terminals Antalya	6	6	6	6	8
TCDD İzmir Alsancak	12	12	12	8	8
Nemport	7	7	7	7	10
Bandırma Çelebi	9	9	9	9	9
Gemport	10	10	10	14	14

Container Storage Area

These are areas where containers for import and export products are temporarily stored until the ship arrives or the products are delivered to their owners by other means of transportation. The container storage area is one of the parameters that significantly affects port efficiency. The data on the container storage areas of the container terminals included in the analysis are presented in Table 5.

Table 5. Container storage areas

Port	2018	2019	2020	2021	2022
Assan Port	225.000	225.000	225.000	225.000	225.000
Limak Port	400.000	400.000	400.000	400.000	400.000
MIP Port	1253.355	1253.355	1253.355	1253.355	1253.355
Q Terminals Antalya	201.125	201.125	201.125	200.141	203.920
TCDD İzmir Alsancak	221.000	221.000	221.000	221.000	221.000
Nemport	100.000	100,000	100.000	100.000	240.000
Bandırma Çelebi	268.348	268.348	268.348	268.348	268.348
Gemport	868.000	868.000	868.000	1250.000	1250.000

Number of Berths

One of the primary goals of container ship operators, as with all ships, is to minimize the time a vessel spends in port. This idea is also a fundamental goal for port operators. Depending on the number of berths, multiple ships can operate simultaneously. Additionally, as the number of berths increases, the number of cranes and personnel will also increase. Therefore, the number of berths is an essential factor in the efficiency of a container terminal. The number of berths at the container terminals evaluated in the analysis is presented in Table 6.

Table 6. Number of berths at evaluated container terminals (units)

Port	2018	2019	2020	2021	2022
Assan Port	4	4	4	4	4
Limak Port	8	8	8	8	8
MIP Port	21	21	21	21	21
Q Terminals Antalya	8	8	8	8	9
TCDD Izmir Alsancak	9	9	9	9	9
Nemport	4	4	4	4	6
Bandırma Çelebi	12	12	12	12	12
Gemport	10	10	10	10	10

Number of Stacking Vehicles

The capacity and quantity of equipment used in both transporting and stacking containers on-site are considered crucial factors affecting the efficiency of a container terminal. Stacking equipment is essential in ports with a high number of incoming ships, large capacity and area, significant performance requirements, and the need for detailed planning. The number of stacking vehicles at the container terminals evaluated in the analysis is presented in Table 7.

Table 7. Number of stacking vehicles at evaluated container terminals (units)

Port	2018	2019	2020	2021	2022
Assan Port	19	19	19	19	19
Limak Port	42	42	43	56	56
MIP Port	70	70	70	76	76
Q Terminals Antalya	57	57	57	57	57
TCDD Izmir Alsancak	82	82	82	61	61
Nemport	65	65	65	65	74
Bandırma Çelebi	22	22	22	22	22
Gemport	68	68	68	79	79

Handled Container Volume

The only output value used in the study is the annual handled container volume (TEU). Container handling refers to the necessary loading and unloading services for containers. The primary goal of a port is to handle as much cargo as possible to generate maximum revenue and profit for the port. Therefore, this dimension is an essential criterion for measuring the efficiency of a container terminal. The volume of handled containers is the main indicator of port efficiency and how effectively input variables are used. The annual container handling volumes of the container terminals evaluated in the analysis are presented in Table 8.

Table 8. Annual container handling volume at evaluated container terminals (TEU)

Port	2018	2019	2020	2021	2022
Assan Port	225.496	248.594	244.643	214.484	177.661
Limak Port	311.261	379.809	466.184	464.571	481.883
MIP Port	1,722.711	1,939.029	2,009.724	2,097.349	2,020.967
Q Terminals Antalya	186.290	148.750	123.983	116.786	93.016
TCDD Izmir Alsancak	647.715	605.727	531.687	529.131	406.081
Nemport	390.071	430.014	484.371	544.568	558.648
Bandırma Çelebi	35.695	18.581	13.340	6.981	10.616
Gemport	524.652	547.190	570.427	682.064	676.782

The results of the Data Envelopment Analysis (DEA) were examined and interpreted for each model separately in terms of efficiency values, reference groups, residual values, and input and output weights. The analysis results are detailed in the following sections.

Input-Oriented CCR Analysis Results

According to the model developed by Charnes, Cooper, and Rhodes, the results of the input-oriented analysis showing the efficiency status of the selected ports as decision-making units over the years are presented in the Figure 2.

The results of the input-oriented CCR analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, are presented in the Table 9.

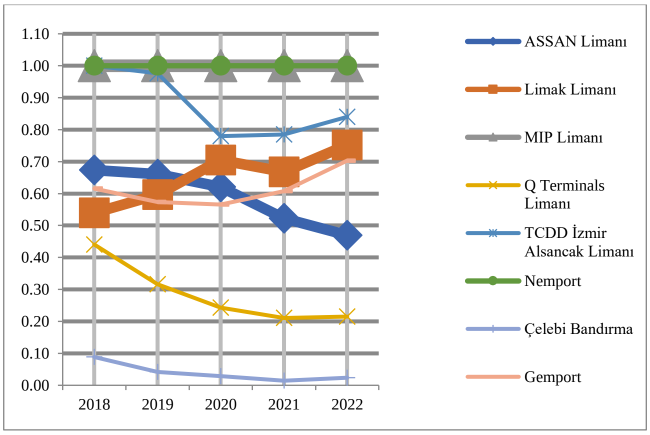

Figure 2. Efficiency status graph according to the input-oriented CCR analysis model

Table 9. Efficiency scores, reference groups, and ratios according to the input-oriented CCR analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Assan Port	0.6735	0.6612	0.6210	0.5221	0.4697	MIP (0.11) Nemport (0.7)	MIP (0.11) Nemport (0.07)	MIP (0.10) Nemport (0.07)	MIP (0.09) Nemport (0.05)	MIP (0.08) Nemport (0.04)
Limak Port	0.5396	0.5966	0.7047	0.6682	0.7518	MIP (0.16) TCDD İzmir (0.06)	MIP (0.18) Nemport (0.07)	MIP (0.22) Nemport (0.08)	MIP (0.21) Nemport (0.08)	MIP (0,23) Nemport (0.07)
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.4406	0.3160	0.2429	0.2106	0.2151	MIP (0.05) Nemport (0.26)	MIP (0,04) Nemport (0.18)	MIP (0,03) Nemport (0.14)	MIP (0,02) Nemport (0.12)	MIP (0,01) Nemport (0.13)
TCDD Izmir Alsancak Port	1.0000	0.9767	0.7798	0.7845	0.8396	-	MIP (0,09) Nemport (0.98)	MIP (0,07) Nemport (0.79)	MIP (0,09) Nemport (0.63)	MIP (0,03) Nemport (0.62)
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.0885	0.0415	0.0285	0.0144	0.0236	MIP (0,02) TCDD İzmir (0.01)	MIP (0,008) Nemport (0.005)	MIP (0,006) Nemport (0.003)	MIP (0,003) Nemport (0.001)	MIP (0,005) Nemport (0.002)
Gemport	0.6162	0.5735	0.5657	0.6081	0.7032	MIP (0,23) Nemport (0.31)	MIP (0,22) Nemport (0.29)	MIP (0,21) Nemport (0.29)	MIP (0,19) Nemport (0.52)	MIP (0.33)

The residual values of the variables for each year, berth length, number of cranes, container storage area, number of berths, number of stacking vehicles, and container handling volume according to the input-oriented CCR analysis model, are presented in the Table 10.

Based on the analysis results according to the model developed by Charnes, Cooper, and Rhodes, it is understood that M.I.P. Port and Nemport Port have been efficient throughout the entire analysis period from 2018 to 2022. When examining the efficiency scores and reference group values in Table 9 and the slack values in Table 10 for the container ports evaluated in the study according to the input-oriented CCR model:

Assan Port: The efficiency score decreased from 0.6735 in 2018 to 0.4697 in 2022. To increase efficiency, it should emulate M.I.P. Port by approximately 20% and Nemport Port by approximately 6%. The inefficiency is due to excessive berth length, crane number, and container storage area, which should be reduced as indicated in Table 10.

Limak Port: The efficiency score increased from 0.5396 in 2018 to 0.7518 in 2022, except for a drop to 0.6682 in 2021. To improve efficiency, it should emulate M.I.P. Port by approximately 20%, Nemport Port by 8%, and TCDD Izmir Alsancak Port by 6%. The inefficiency is due to excessive crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.4406 in 2018 to 0.2106 in 2021 and slightly increased to 0.2151 in 2022. To increase efficiency, it should emulate Nemport Port by approximately 17% and M.I.P. Port by 3%. The inefficiency is due to excessive berth length, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

TCDD Izmir Alsancak Port: It was efficient in 2018, but the efficiency score dropped in 2019 and 2020, and then increased to 0.8396 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 76% and M.I.P. Port by 7%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: It has the lowest efficiency score throughout the period, dropping from 0.0885 in 2018 to 0.0144 in 2021, with a slight increase to 0.0236 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 0.8%, Nemport Port by 0.4%, and TCDD Izmir Alsancak Port by 1%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 10.

Gemport: The efficiency score decreased from 0.6162 in 2018 to 0.5657 in 2020 and then increased to 0.7032 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 35% and M.I.P. Port by 24%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 9.

Table 10. Residual values of variables according to the input-oriented CCR analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	20.24	0.24	997.90	0.00	0.00	0.00
	2019	19.87	0.23	979.67	0.00	0.00	0.00
	2020	18.66	0.22	920.17	0.00	0.00	0.00
	2021	21.56	0.23	0.00	0.01	0.00	0.00
	2022	9.85	0.16	0.00	0.02	0.00	0.00
Limak Port	2018	0.00	7.30	0.00	0.37	6.28	0.00
	2019	0.00	8.30	0.00	0.61	7.60	0.00
	2020	0.00	9.81	0.00	0.72	9.68	0.00
	2021	0.00	9.30	0.00	0.69	16.62	0.00
	2022	0.00	10.50	0.00	0.84	19.82	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	46.68	0.00	0.00	1.45	4.99	0.00
	2019	33.48	0.00	0.00	1.04	3.58	0.00
	2020	25.74	0.00	0.00	0.80	2.75	0.00
	2021	22.47	0.00	0.00	0.69	2.22	0.00
	2022	0.00	0.25	0.00	0.94	1.89	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	3.22	0.00	2.88	9.38	0.00
	2020	0.00	2.57	0.00	2.30	7.49	0.00
	2021	129.20	0.35	0.00	2.68	0.00	0.00
	2022	38.36	0.00	0.00	3.22	2.95	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	191.94	0.39	0.00	0.62	0.00	0.00
	2019	89.48	0.19	0.00	0.30	0.00	0.00
	2020	61.38	0.13	0.00	0.21	0.00	0.00
	2021	31.23	0.07	0.00	0.10	0.00	0.00
	2022	50.83	0.11	0.00	0.17	0.00	0.00
Gemport	2018	131.50	0.00	210,366.86	0.00	5.24	0.00
	2019	122.40	0.00	195,809.65	0.00	4.88	0.00
	2020	120.72	0.00	193,119.75	0.00	4.81	0.00
	2021	45.02	1.65	468,660.30	0.00	0.00	0.00
	2022	313.11	4.15	459,336.87	0.00	30.11	0.00

Output-Oriented CCR Analysis Results

According to the model developed by Charnes, Cooper, and Rhodes, the output-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 3. When examining the efficiency scores and reference group values in Table 11 and the slack values in Table 12 for the container ports evaluated in the study according to the output-oriented CCR model:

Assan Port: The efficiency score decreased from 0.6735 in 2018 to 0.4697 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 17% and Nemport Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and container storage area, which should be reduced as indicated in Table 12.

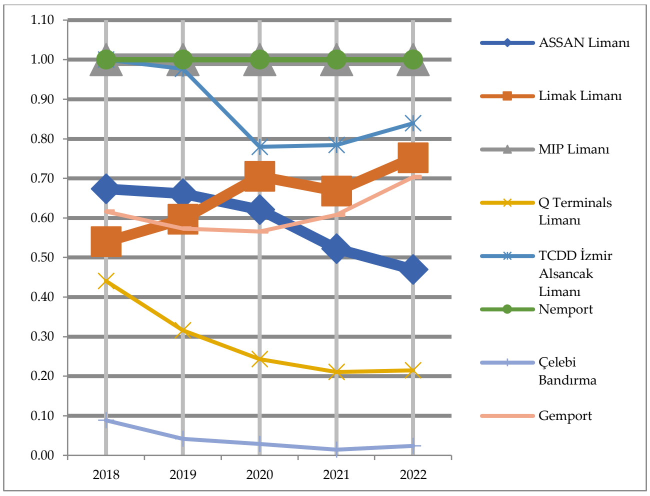

Figure 3. Efficiency status graph according to the output-oriented CCR analysis model

Table 11. Efficiency scores, reference groups, and ratios according to the output-oriented CCR analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	**2019**	2020	**2018**	**2019**	2018	**2018**	**2019**	2021	**2018**
Assan Port	0.6735	0.6612	0.6210	0.5221	0.4697	MIP (0.17) Nemport (0.10)	MIP (0.17) Nemport (0.11)	MIP (0.17) Nemport (0.11)	MIP (0.17) Nemport (0.09)	MIP (0.16) Nemport (0.09)
Limak Port	0.5396	0.5966	0.7047	0.6682	0.7518	MIP (0.30) TCDD İzmir (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.30) Nemport (0.09)
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.4406	0.3160	0.2429	0.2106	0.2151	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.05) Nemport (0.60)
TCDD Izmir Alsancak Port	1.0000	0.9767	0.7798	0.7845	0.8396	-	MIP (0.10) Nemport (1.01)	MIP (0.10) Nemport (1.01)	MIP (0.11) Nemport (0.80)	MIP (0.03) Nemport (0.74)
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.0885	0.0415	0.0285	0.0144	0.0236	MIP (0.20) TCDD İzmir (0.10)	MIP (0.20) Nemport (0.12)	MIP (0.20) Nemport (0.12)	MIP (0.20) Nemport (0.10)	MIP (0.20) Nemport (0.10)
Gemport	0.6162	0.5735	0.5657	0.6081	0.7032	MIP (0.38) Nemport (0.51)	MIP (0.38) Nemport (0.51)	MIP (0.38) Nemport (0.51)	MIP (0.31) Nemport (0.85)	MIP (0.48)

Limak Port: The efficiency score increased from 0.5396 in 2018 to 0.7518 in 2022, except for a drop to 0.6682 in 2021. To improve efficiency, it should emulate M.I.P. Port by approximately 31%, Nemport Port by 11%, and TCDD Izmir Alsancak Port by 12%. The inefficiency is due to excessive crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 12.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.4406 in 2018 to 0.2106 in 2021 and slightly increased to 0.2151 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 58% and M.I.P. Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 12.

TCDD Izmir Alsancak Port: It was efficient in 2018, but the efficiency score dropped in 2019 and 2020, and then increased to 0.8396 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 89% and M.I.P. Port by 9%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 12.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: It has the lowest efficiency score throughout the period, dropping from 0.0885 in 2018 to 0.0144 in 2021, with a slight increase to 0.0236 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 20%, Nemport Port by 11%, and TCDD Izmir Alsancak Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 12.

Gemport: The efficiency score decreased from 0.6162 in 2018 to 0.5657 in 2020 and then increased to 0.7032 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 59% and M.I.P. Port by 39%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 12.

Input-Oriented BCC Analysis Results

According to the model developed by Banker, Charnes, and Cooper, the input-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 4.

Table 12. Residual values of variables according to the output-oriented CCR analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	30.05	0.35	1481.73	0.00	0.00	0.00
	2019	30.05	0.35	1481.73	0.00	0.00	0.00
	2020	30.05	0.35	1481.73	0.00	0.00	0.00
	2021	41.30	0.44	0.00	0.02	0.00	0.00
	2022	20.98	0.34	0.00	0.05	0.00	0.00
Limak Port	2018	0.00	13.54	0.00	0.69	11.63	0.00
	2019	0.00	13.92	0.00	1.03	12.74	0.00
	2020	0.00	13.92	0.00	1.03	13.74	0.00
	2021	0.00	13.92	0.00	1.03	24.88	0.00
	2022	0.00	13.96	0.00	1.12	26.36	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	105.95	0.00	0.00	3.28	11.32	0.00
	2019	105.95	0.00	0.00	3.28	11.32	0.00
	2020	105.95	0.00	0.00	3.28	11.32	0.00
	2021	106.68	0.00	0.00	3.29	10.56	0.00
	2022	0.00	1.16	0.00	4.39	8.77	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	3.30	0.00	2.95	9.61	0.00
	2020	0.00	3.30	0.00	2.95	9.61	0.00
	2021	164.69	0.44	0.00	3.42	0.00	0.00
	2022	45.69	0.00	0.00	3.83	3.51	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	2168.94	4.45	0.00	6.97	0.00	0.00
	2019	2155.73	4.69	0.00	7.23	0.00	0.00
	2020	2155.73	4.69	0.00	7.23	0.00	0.00
	2021	2172.64	4.81	0.00	7.28	0.00	0.00
	2022	2150.90	4.71	0.00	7.31	0.00	0.00
Gemport	2018	213.42	0.00	341409.49	0.00	8.51	0.00
	2019	213.42	0.00	341409.49	0.00	8.51	0.00
	2020	213.42	0.00	341409.49	0.00	8.51	0.00
	2021	74.03	2.72	770715.77	0.00	0.00	0.00
	2022	445.24	5.90	653164.29	0.00	42.81	0.00

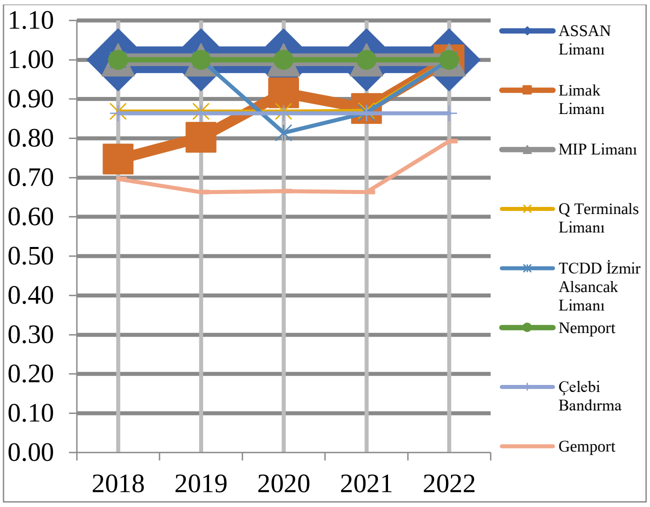

Figure 4. Efficiency status graph according to the input-oriented BCC analysis model

The results of the input-oriented BCC analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, are presented in Table 13. The slack values for these ports are shown in Table 14. Upon examining the efficiency scores in Table 13, it is understood that Limak Port and Q Terminals Port were efficient in 2022, TCDD Izmir Alsancak Port in 2018, 2019, and 2022, and ASSAN Port, M.I.P. Port, and Nemport Port were efficient throughout the entire analysis period from 2018 to 2022. The findings are as follows:

Assan Port: It has been efficient throughout the period.

Limak Port: The efficiency score increased from 0.7466 in 2018 to 1.0000 in 2022, except for a drop to 0.8758 in 2021. To improve efficiency, it should emulate ASSAN Port by approximately 74%, M.I.P. Port by 6%, Nemport Port by 61% (2021), and TCDD Izmir Alsancak Port by 19%. The inefficiency is due to excessive crane numbers, container storage area, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score remained constant at 0.8682 from 2018 to 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate ASSAN Port by approximately 60% and Nemport Port by 40%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

TCDD Izmir Alsancak Port: It was efficient in 2018 and 2019, but the efficiency score dropped to 0.8140 in 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 74%, ASSAN Port by 21%, and M.I.P. Port by 5%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: The efficiency score remained constant at 0.8636 throughout the period. To improve efficiency, it should emulate ASSAN Port by 100%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and berth numbers, which should be reduced as indicated in Table 13.

Table 13. Efficiency scores, reference groups, and ratios according to the input-oriented BCC analysis model

Decision-Making Units	**Efficiency Score**					**Reference Group and Ratio**				
	2018	**2019**	2020	**2018**	**2019**	2018	**2018**	**2019**	2021	**2018**
Assan Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Limak Port	0.7466	0.8026	0.9156	0.8758	1.0000	ASSAN (0.80) MIP (0.01) TCDD İzmir (0.19)	ASSAN (0.92) MIP (0.08)	ASSAN (0.87) MIP (0.13)	ASSAN (0.35) MIP (0.03) Nemport (0.61)	-
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.8682	0.8682	0.8682	0.8701	1.0000	ASSAN (0.60) Nemport (0.40)	ASSAN (0.60) Nemport (0.40)	ASSAN (0.60) Nemport (0.40)	ASSAN (0.59) Nemport (0.41)	-
TCDD Izmir Alsancak Port	1.0000	1.0000	0.8140	0.8652	1.0000	-	-	ASSAN (0.14) MIP (0.05) Nemport (0.80)	ASSAN (0.28) MIP (0.05) Nemport (0.67)	-
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.8636	0.8636	0.8636	0.8636	0.8636	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)
Gemport	0.6964	0.6627	0.6657	0.6630	0.7928	ASSAN (0.59) MIP (0.17) Nemport (0.23)	ASSAN (0.64) MIP (0.15) Nemport (0.21)	ASSAN (0.64) MIP (0.15) Nemport (0.21)	ASSAN (0.31) MIP (0.15) Nemport (0.54)	ASSAN (0.37) MIP (0.18) Nemport (0.45)

Gemport: The efficiency score decreased from 0.6964 in 2018 to 0.6627 in 2019 and then increased to 0.7928 in 2022. To improve efficiency, it should emulate ASSAN Port by 51%, Nemport Port by 33%, and M.I.P. Port by 16%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 13.

Output-Oriented BCC Analysis Results

According to the model developed by Banker, Charnes, and Cooper, the output-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 5.

Table 14. Residual values of variables according to the input-oriented BCC analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	20.98	0.34	0.00	0.05	0.00	0.00
Limak Port	2018	0.00	9.31	65832.60	0.88	0.00	0.00
	2019	0.00	10.98	11038.38	1.02	10.49	0.00
	2020	0.00	12.59	4932.77	1.07	13.61	0.00
	2021	0.00	11.26	169628.21	2.47	0.00	0.00
	2022	0.00	13.96	0.00	1.12	26.36	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	104.68	0.00	0.00	2.95	11.95	105540.65
	2019	104.68	0.00	0.00	2.95	11.95	172968.31
	2020	104.68	0.00	0.00	2.95	11.95	217286.30
	2021	105.43	0.00	0.00	2.96	11.88	231996.68
	2022	0.00	1.16	0.00	4.39	8.77	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	2.66	0.00	2.41	8.11	0.00
	2021	131.04	0.26	0.00	2.95	0.00	0.00
	2022	45.69	0.00	0.00	3.83	3.51	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	1847.59	3.77	6755.09	6.36	0.00	189801.00
	2019	1847.59	3.77	6755.09	6.36	0.00	230013.00
	2020	1847.59	3.77	6755.09	6.36	0.00	231303.00
	2021	1847.59	3.77	6755.09	6.36	0.00	207503.00
	2022	2150.90	4.71	0.00	7.31	0.00	0.00
Gemport	2018	154.92	0.00	229222.25	0.00	8.77	0.00
	2019	148.23	0.00	217065.64	0.00	8.70	0.00
	2020	148.82	0.00	218137.47	0.00	8.71	0.00
	2021	36.99	1.67	511426.67	0.00	0.00	0.00
	2022	445.24	5.90	653164.29	0.00	42.81	0.00

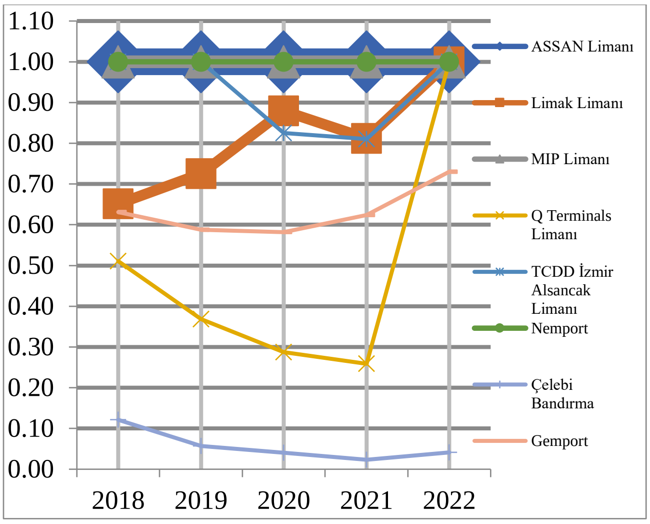

Figure 5. Efficiency Status Graph According to the Output-Oriented BCC Analysis Model

The results of the output-oriented BCC analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, will provide further insights into their performance and areas for improvement. Based on the results of the output-oriented BCC analysis model, the efficiency scores, reference groups, and slack values for the container terminals evaluated over the years are presented in Table 15 and Table 16.

Upon examining the efficiency scores in Table 15, it is understood that Limak Port and Q Terminals Port were efficient in 2022, TCDD Izmir Alsancak Port in 2018, 2019, and 2022, and ASSAN Port, M.I.P. Port, and Nemport Port were efficient throughout the entire analysis period from 2018 to 2022. The findings are as follows:

ASSAN Port: It has been efficient throughout the period.

Limak Port: The efficiency score increased from 0.6510 in 2018 to 1.0000 in 2022, except for a drop to 0.8116 in 2021. To improve efficiency, it should emulate ASSAN Port by approximately 62%, M.I.P. Port by 13%, Nemport Port by 72% (2021), and TCDD Izmir Alsancak Port by 29%. The inefficiency is due to excessive crane numbers, container storage area, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

MIP Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.5105 in 2018 to 0.2587 in 2021 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate ASSAN Port by approximately 46%, Nemport Port by 50%, and M.I.P. Port by 4%. The inefficiency is due to excessive berth length, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

Table 15. Efficiency scores, reference groups, and ratios according to the output-oriented BCC analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	2019	2020	2018	2019	2018	2018	2019	2021	2018
Assan Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Limak Port	0.6510	0.7250	0.8792	0.8116	1.0000	ASSAN (0.62) MIP (0.09) TCDD İzmir (0.29)	ASSAN (0.83) MIP (0.17)	ASSAN (0.83) MIP (0.17)	ASSAN (0.21) MIP (0.07) Nemport (0.72)	-
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.5105	0.3684	0.2870	0.2587	1.0000	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	-
TCDD Izmir Alsancak Port	1.0000	1.0000	0.8251	0.8103	1.0000	-	-	MIP (0.10) Nemport (0.90)	ASSAN (0.11) MIP (0.09) Nemport (0.80)	-
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.1213	0.0570	0.0409	0.0233	0.0409	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)	ASSAN (0.94) MIP (0.04) TCDD İzmir (0.02)	ASSAN (0.94) MIP (0.04) TCDD İzmir (0.02)	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)
Gemport	0.6312	0.5880	0.5818	0.6243	0.7302	ASSAN (0.18) MIP (0.35) Nemport (0.47)	ASSAN (0.18) MIP (0.35) Nemport (0.47)	ASSAN (0.18) MIP (0.35) Nemport (0.47)	MIP (0.35) Nemport (0.65)	ASSAN (0.12) MIP (0.28) Nemport (0.60)

TCDD Izmir Alsancak Port: It was efficient in 2018 and 2019, but the efficiency score dropped to 0.8103 in 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 85%, ASSAN Port by 5%, and M.I.P. Port by 10%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: The efficiency score decreased from 0.1213 in 2018 to 0.0233 in 2021 and then increased to 0.0409 in 2022. To improve efficiency, it should emulate ASSAN Port by 95%, M.I.P. Port by 4%, and TCDD Izmir Alsancak Port by 1%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 15.

Gemport: The efficiency score decreased from 0.6312 in 2018 to 0.5818 in 2020 and then increased to 0.7302 in 2022. To improve efficiency, it should emulate ASSAN Port by 13%, Nemport Port by 53%, and M.I.P. Port by 34%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 15.

Table 16. Residual values of variables according to the output-oriented BCC analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Limak Port	2018	0.00	12.47	79320.12	0.95	0.00	0.00
	2019	0.00	13.79	373.68	1.11	14.34	0.00
	2020	0.00	13.79	373.68	1.11	15.34	0.00
	2021	0.00	12.91	189408.56	2.76	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	115.72	0.00	0.00	3.36	12.95	0.00
	2019	115.72	0.00	0.00	3.36	12.95	0.00
	2020	115.72	0.00	0.00	3.36	12.95	0.00
	2021	116.40	0.00	0.00	3.37	12.63	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	93.75	3.95	0.00	3.22	16.48	0.00
	2021	160.18	0.40	0.00	3.42	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	2131.82	4.34	0.00	7.22	0.00	0.00
	2019	2130.19	4.38	0.00	7.25	0.00	0.00
	2020	2130.19	4.38	0.00	7.25	0.00	0.00
	2021	2133.60	4.40	0.00	7.26	0.00	0.00
	2022	2131.04	4.39	0.00	7.26	0.00	0.00
Gemport	2018	215.29	0.00	338874.71	0.00	9.35	0.00
	2019	215.29	0.00	338874.71	0.00	9.35	0.00
	2020	215.29	0.00	338874.71	0.00	9.35	0.00
	2021	161.76	3.47	742933.53	0.00	10.12	0.00
	2022	0.00	2.73	725699.75	0.00	10.88	0.00

Table 17. Average efficiency scores by year and analysis model

Decision-Making Unit	Year	CCR-I	CCR-O	BCC-I	BCC-O	Average Efficiency Score by Analysis Model
Assan Port	2018	0.6735	0.6735	1.0000	1.0000	0.8367
	2019	0.6612	0.6612	1.0000	1.0000	0.8306
	2020	0.6210	0.6210	1.0000	1.0000	0.8105
	2021	0.5221	0.5221	1.0000	1.0000	0.7611
	2022	0.4697	0.4697	1.0000	1.0000	0.7348
	Average Efficiency Score by Year	0.5895	0.5895	1.0000	1.0000	0.7947
Limak Port	2018	0.5396	0.5396	0.7466	0.6510	0.6192
	2019	0.5966	0.5966	0.8026	0.7250	0.6802
	2020	0.7047	0.7047	0.9156	0.8792	0.8011
	2021	0.6682	0.6682	0.8758	0.8116	0.7560
	2022	0.7518	0.7518	1.0000	1.0000	0.8759
	Average Efficiency Score by Year	0.6522	0.6522	0.8681	0.8134	0.7465
MIP Port	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	1.0000	1.0000	1.0000	1.0000	1.0000
	2020	1.0000	1.0000	1.0000	1.0000	1.0000
	2021	1.0000	1.0000	1.0000	1.0000	1.0000
	2022	1.0000	1.0000	1.0000	1.0000	1.0000
	Average Efficiency Score by Year	1.0000	1.0000	1.0000	1.0000	1.0000
Q Terminals Port	2018	0.4406	0.4406	0.8682	0.5105	0.5650
	2019	0.3160	0.3160	0.8682	0.3684	0.4671
	2020	0.2429	0.2429	0.8682	0.2870	0.4103
	2021	0.2106	0.2106	0.8701	0.2587	0.3875
	2022	0.2151	0.2151	1.0000	1.0000	0.6076
	Average Efficiency Score by Year	0.2850	0.2850	0.8949	0.4849	0.4875
TCDD İzmir Alsancak Port	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	0.9767	0.9767	1.0000	1.0000	0.9884
	2020	0.7798	0.7798	0.8140	0.8251	0.7997
	2021	0.7845	0.7845	0.8652	0.8103	0.8111
	2022	0.8396	0.8396	1.0000	1.0000	0.9198
	Average Efficiency Score by Year	0.8761	0.8761	0.9359	0.9271	0.9038
Nemport	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	1.0000	1.0000	1.0000	1.0000	1.0000
	2020	1.0000	1.0000	1.0000	1.0000	1.0000
	2021	1.0000	1.0000	1.0000	1.0000	1.0000
	2022	1.0000	1.0000	1.0000	1.0000	1.0000
	Average Efficiency Score by Year	1.0000	1.0000	1.0000	1.0000	1.0000
Çelebi Bandırma	2018	0.0885	0.0885	0.8636	0.1213	0.2905
	2019	0.0415	0.0415	0.8636	0.0570	0.2509
	2020	0.0285	0.0285	0.8636	0.0409	0.2404
	2021	0.0144	0.0144	0.8636	0.0233	0.2289
	2022	0.0236	0.0236	0.8636	0.0409	0.2380
	Average Efficiency Score by Year	0.0393	0.0393	0.8636	0.0567	0.2497
Gemport	2018	0.6162	0.6162	0.6964	0.6312	0.6400
	2019	0.5735	0.5735	0.6627	0.5880	0.5994
	2020	0.5657	0.5657	0.6657	0.5818	0.5947
	2021	0.6081	0.6081	0.6630	0.6243	0.6259
	2022	0.7032	0.7032	0.7928	0.7302	0.7324
	Average Efficiency Score by Year	0.6133	0.6133	0.6961	0.6311	0.6385

As a conclusion; this study evaluated the relative efficiency levels of ASSAN Port, Limak Port, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport, Bandırma Çelebi Port, and Gemport container terminals using input and output-oriented CCR and BCC models of Data Envelopment Analysis (DEA). The average efficiency scores by year and analysis model for the container terminals evaluated are presented in Table 17.

Analyzing the average efficiency scores of the container terminals examined within the scope of the study according to the years and according to the analysis model, it is seen that M.I.P. Port and Nemport Port are efficient. According to the average efficiency values of the other container terminals, TCDD Izmir (0.9038), Assan (0.7947), Limak (0.7465), Gemport (0.6385), Q Terminals (0.4875), and Çelebi Bandırma (0.2497) can be listed in descending order.

CONCLUSION

In today's world, where approximately three-quarters of global trade is conducted by sea, the importance of maritime logistics is increasing day by day. Considering that container transportation is the most preferred method in maritime logistics today, and ports are one of the most important factors in maritime transportation, this thesis study was conducted to analyze the current status of container terminals in the Iskenderun Bay, and identify measures that can be taken to ensure effective and efficient operations. The Data Envelopment Analysis (DEA) application was performed using the Open Source DEA package program. The findings of this study emphasize the importance of performance measurement for efficient and effective operation of container terminals, considering the significance of maritime trade for our country. Using DEA in port performance analysis is a correct initiative. Through these measurements, port operators can learn about their current status, strengths and weaknesses, overused inputs, and insufficient outputs, allowing them to develop strategies and plans to minimize wasted resources.

Performance analysis of the eight ports within the scope of the study was conducted using both input and output-oriented CCR and BCC models. According to the analysis results, the efficiency levels of the container terminals subject to the analysis, the reference terminals and their proportions, and the inputs that can be reduced to achieve efficiency were discussed.

The relative performance evaluation of ASSAN Port, Limak Port, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport, Bandırma Çelebi Port, and Gemport container terminals was conducted using DEA. The same ports were found to be efficient in both input and output-oriented CCR and BCC model applications.

This study covered a five-year period from 2018-2022, providing an advantage for calculating the average efficiency of the evaluated container terminals. Seasonal errors in input and output values or measurement errors caused by uncontrollable factors such as COVID-19 were minimized. Additionally, average efficiency scores by analysis model were calculated, and the general efficiency level rankings of the evaluated terminals were established.

After the analysis calculations, it was found that M.I.P. Port and Nemport Port were efficient among the evaluated container terminals. The current efficiency scores of the inefficient container terminals and the measures they need to take to improve were determined.

In similar studies conducted in past periods at container ports in Türkiye, it has been observed that results similar to those obtained in this research were achieved. With this application, it was concluded whether the evaluated container terminals were efficient or not. One significant finding of the study is that inefficient container terminals often need to reduce the number of cranes, berths, and stacking vehicles, as these inputs were found to be ineffectively used. A total of 160 efficiency values were calculated for eight different container terminals over a five-year period using four different methods, with only 62 of these values indicating efficiency.

For the container terminals in the Iskenderun Bay, it was found that ASSAN Port was efficient 10 times (in BCC-I and BCC-O models) with an average efficiency score of 0.7947, and Limak Port was efficient only twice (in 2022 in BCC-I and BCC-O models) with an average efficiency score of 0.7465. This indicates that both ports in the Iskenderun Bay are not efficient in average data but have high efficiency scores and can become efficient with necessary measures.

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Compliance with Ethical Standards

Authors' Contributions

This study is a part of M.Sc. thesis of the first author, which was carried out under the supervision of the second author. All authors contributed to the study conception and design. Data collection was performed by Engin Dal, analysis was conducted by Vahit Çalışır. The first draft of the manuscript was written by Vahit Çalışır. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

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

Data Availability

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

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