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### Performance Evaluation of Airports During the COVID-19 Pandemic<sup>1</sup>

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**Abstract:** Globalisation, international trade, tourism, and economic and technological advances have contributed to the development of the aviation industry. In a globally competitive environment, airports need to use their resources efficiently and evaluate their performance to compete with their rivals. Data Envelopment Analysis (DEA) is a widely used method in the performance evaluation of airports. This study was aimed to measure the performance and ranking of selected major international airports in 2019 and the first quarter of 2020 using the DEA method, the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) method, and the Evaluation Based on Distance from Average Solution (EDAS) method. Efficiency analysis has been carried out using CCR-DEA models. Later, performance evaluation of the alternatives was made according to the TOPSIS and EDAS methods. In this study, the ranking of the airports has been compiled according to the results of the DEA, TOPSIS and EDAS methods. The study found that the use of the DEA method together with Multi-Criteria Decision-Making (MCDM) methods such as TOPSIS and EDAS for the performance evaluation of airports allows a full and clear ranking of decision-making units (DMUs).

**Keywords:** Airport performance, COVID-19 pandemic, DEA, EDAS, TOPSIS

**JEL classification codes:** C14, C61, C67, L93

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Article submitted June 28, 2021, revision received October 11, 2021,  
accepted for publication October 25, 2021.

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<sup>1</sup> The author would like to thank the organisations, websites and airports which provided the data for this study.

## Ocena wyników portów lotniczych w czasie pandemii COVID-19

**Streszczenie:** Globalizacja, handel międzynarodowy, turystyka oraz postęp gospodarczy i technologiczny przyczyniły się do rozwoju branży lotniczej. By móc skutecznie rywalizować w globalnie konkurencyjnym środowisku, porty lotnicze muszą efektywnie wykorzystywać swoje zasoby i dokonywać oceny swoich wyników. W przypadku portów lotniczych szeroko stosowaną metodą oceny wyników jest Data Envelopment Analysis (DEA). Niniejsze badanie miało na celu określenie wyników i pozycji rankingowej wybranych głównych międzynarodowych portów lotniczych w 2019 r. i I kwartale 2020 r. za pomocą metody DEA, a także metod TOPSIS i EDAS. Analiza efektywności została przeprowadzona z wykorzystaniem modeli CCR-DEA. Następnie dokonano oceny wyników alternatywnych za pomocą metod TOPSIS i EDAS. Ranking lotnisk został natomiast opracowany na podstawie uzyskanych wyników badań przeprowadzonych trzema metodami: DEA, TOPSIS i EDAS. Badanie wykazało, że zastosowanie do oceny wydajności portów lotniczych metody DEA wraz z metodami *Multi-Criteria Decision-Making* (MCDM) takimi jak TOPSIS i EDAS, pozwala na uzyskanie pełnego i czytelnego rankingu jednostek decyzyjnych (DMU).

**Słowa kluczowe:** wyniki portów lotniczych, pandemia COVID-19, DEA, EDAS, TOPSIS

**Kody klasyfikacji JEL:** C14, C61, C67, L93

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Artykuł złożony 28 czerwca 2021 r., w wersji poprawionej nadesłany 11 października 2021 r.,  
zaakceptowany 25 października 2021 r.

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## Introduction

The aviation sector contributes to economic growth and employment, while also facilitating international trade and tourism [Zajac, 2016; Abate, 2016; Tolcha et al., 2020]. The aviation industry is one of the fastest growing sectors in the global economy and people have become more frequent users of air travel recently [Babic et al., 2017]. International trade, visa agreements, tourism, social media marketing, sports competitions, and scientific events contribute to the development of international air passenger and freight transport [Zajac, 2016; Seo, Park, 2018; Spasojevic et al., 2018]. Many countries encourage the establishment of airports and airline companies. Recent years have seen investment in new airports by both the state and the private sectors, the expansion of aircraft fleets, an increase in employment, and the entry of new companies in the aviation industry [Zajac, 2016; İnan, 2018; Roucello et al., 2020].

Today airports have to adapt faster to changing global environments in order to survive in the aviation industry. Therefore, local governments continue to explore ways to operate airports efficiently [Keskin, Köksal, 2019]. An increased number of airline companies, combined with the convenience and time saving in airline transportation, have made airport operations attractive. Airport managers have begun to look for ways to better serve their customers and compete with their rivals. This quest brought along the concept of

the efficiency of airports [Peker, Baki, 2009]. Airports are an important factor in promoting economic growth, employment and competitiveness. Besides, airports contribute to the development of international trade. Therefore, many countries are developing policies to increase the efficiency of airports [Stichhauerova, Pelloneova, 2019].

Airport efficiency assessment has recently become an emerging area of research. Efficiency analyses are important for airlines, airports, passengers, governments and stakeholders in the aviation industry. Financial and operational efficiency is evaluated to examine the efficiency of airports [Lai et al., 2015]. However, like many other industries, the aviation industry around the world has been negatively affected by COVID-19 [Suau-Sanchez et al., 2020; Akbar, Kisilowski, 2020; Serrano, Kazda, 2020; Samancı et al., 2021; Bartle et al., 2021]. Organisations such as the International Air Transport Association (IATA), Airport Council International (ACI), the International Civil Aviation Organisation (ICAO) and Eurocontrol have reported that airline passenger and aviation sector revenues have decreased worldwide due to the COVID-19 epidemic. Also, it has been stated that airports have suffered a revenue loss of approximately USD 112 billion, while airlines have lost approximately USD 118 billion in revenue due to COVID-19. Besides, approximately 197 million jobs were lost in the travel and tourism sector in 2020 due to the negative impact of COVID-19 [ACI, 2021; Eurocontrol, 2021; IATA, 2021; ICAO, 2021; URL1-URL8, 2021]. COVID-19 emerged in the Wuhan province of China on December 19, 2019 and was subsequently declared a global epidemic by the World Health Organisation [Tehci, Ersoy 2020]. COVID-19 is of concern to the international public and has become a serious medical problem [Zhou, Chen, 2020].

Performance analysis is a concept used to identify how efficiently companies use their sources. Recently, efficiency analysis has been used to conduct performance evaluations of firms and organisations. The DEA method is one of the widely used methods to measure efficiency [Altın, 2014; Ersoy, 2021]. The DEA method has many application fields such as health, logistics, finance, education, international trade, production, aviation, and energy [Liu et al., 2013; Merkert, Mangia, 2014; Choi et al., 2015; Karimi and Barati, 2018; Ibanez et al., 2020; Ersoy, 2021]. Another method commonly used in performance evaluation is the TOPSIS method. The TOPSIS method, one of the MCDM methods, is applied in many fields such as production, finance, aviation, location selection, equipment selection, energy, technology and education [Seçme et al., 2009; Sozen et al., 2015; Mardani et al., 2015; Rouyendegh et al., 2018; Wang, Pham, 2019; Kumar, Anbanandam, 2019; Akçetin, Kamacı, 2020; Ersoy, 2021]. The EDAS method is another MCDM method used in performance evaluation. The EDAS method is used for many purposes such as financial performance evaluation, supplier selection, personnel selection, hospital selection, equipment selection, inventory classification, and airline evaluation [Ghorabae et al., 2017; Aggarwal et al., 2018; Yalçın, Pehlivan, 2019; Kundakçı 2019; Ulutaş 2019; Yalçın, Uncu 2019; Aldolou, Perçin, 2020].

In the literature, it is possible to come across many studies evaluating airport performance using the DEA method [Fung et al., 2008; Peker, Baki, 2009; Lozano, Gutierrez, 2011; Pedram, Payan, 2015; Fernandes, Pacheco, 2018; Stichhauerova, Pelloneova, 2019]. There are studies in which performance evaluation is carried out in the field of aviation by using different MCDM methods or by using the DEA and MCDM methods together [Wang et al., 2004; Aydogan, 2011; Lai et al., 2015; Eshtaiwi et al., 2017; Ghorabae et al., 2017; Perçin, Aldolou, 2018; Wang, Pham, 2019; Keskin, Köksal, 2019]. There has been no study in the literature in which performance evaluation in the aviation industry has been made using the DEA, TOPSIS and EDAS methods put together. Therefore, this article seeks to contribute to the literature by using the DEA, TOPSIS and EDAS methods together and investigating whether there is a strong correlation between the results of these methods.

The main research question is how the COVID-19 outbreak has affected the performance of the world's major international airports. The study aims to measure the performance and ranking of 12 selected major international airports for 2019 and the first quarter of 2020 by using the DEA, EDAS and TOPSIS methods. The rest of the study is organised as follows. In the second part, a literature review is given. In the third chapter, the data set and the research methods are explained. The fourth part provides a performance evaluation and a ranking of the airports. In the fifth section, a general evaluation of the study is made.

### Literature Review

In this section of the research, a literature review of the studies carried out using the DEA and MCDM methods is given. It is possible to find many studies in the literature where the DEA method is applied in different areas [Markovits-Somogyi et al., 2011; Liu et al., 2013; Zhang et al., 2014; Emrouznejad, Yang, 2018; Paleckova, 2019; Ibanez et al., 2020].

As in many other industries, it is possible to come across many studies in the aviation sector using the DEA method. Inputs and outputs are needed to apply the DEA method. Therefore, it is necessary to determine the inputs and outputs to be used in the study. For this purpose, research carried out in the aviation industry using the DEA method has been examined. Some of the research has been carried out using the DEA method in the aviation industry and the inputs and outputs of these studies can be seen in Table 1.

There are many studies conducted in different fields using the MCDM method in the literature [Mardani et al., 2015; Ayağ, 2016; Jayant, Sharma, 2018; Chowdhury, Paul, 2020; Shao et al., 2020]. There are studies in which performance evaluation is carried out in different sectors using MCDM methods [Das et al., 2012; Yalcin et al., 2012; Esfahanipour, Davari-Ardakani, 2015; Lee et al., 2017; Ulutaş, 2019; Prashanth et al., 2020; Aldalou, Perçin, 2020]. Some of the studies in which performance evaluation was carried out using MCDM methods in the aviation industry were given in the following paragraphs.

**Table 1. Inputs and outputs of studies on performance evaluation in the aviation industry**

Papers	Units	Inputs	Outputs
Gillen and Lall [2001]	22 major US airports	Number of runways Number of gates Terminal area Number of baggage collection belts Number of public parking spots	Number of passengers Pound of cargo
Pels et al. [2001]	34 European airports	Terminal size Number of aircraft parking Number of check-in desks Number of baggage claims	Number of passengers Aircraft transport movement
Sarkis, Talluri [2004]	44 US airports	Operational costs Number of airport employees Number of gates Number of runways	Passenger flow Total cargo transportation Operational revenue General aviation movement Commercial movement
Yoshida, Fujimoto [2004]	67 Japanese airports	Runway length Terminal size Access cost Number of employees	Number of passengers Number of aircraft movement Cargo handling
Eichinger [2006]	18 Brazilian airports	Number of runways Runway area Apron area Airport area Terminal area Number of gates	Number of aircraft movements Number of passengers
Barros, Dieke [2007]	31 Italian airports	Labour costs Capital invested Operational costs excluding labour costs	Number of planes Number of passengers General cargo Handling receipts Aeronautical sales Commercial sales
Fung et al. [2008]	25 Chinese airports	Runway length Terminal area	Number of passengers Cargo handled Number of aircraft movement
Peker, Baki [2009]	37 Turkish airports	Parking capacity Number of runways Airport area size Number of employees	Number of passengers Total freight
Ablenedo-Rosas, Gemoets [2010]	37 Mexican airports	Average number of passengers per hour Average number of flights per hour	Number of passengers Number of aircraft movements Total freight
Curi et al. [2011]	18 Italian airports	Number of staff Number of runways Apron size	Number of passengers Number of aircraft movements Amount of cargo
Lozano, Gutierrez [2011]	41 Spanish airports	Total runway area Apron capacity Passenger throughput capacity Number of baggage belts Number of check-in counters Number of boarding gates	Number of aircraft movements Passenger movements Cargo handled

Papers	Units	Inputs	Outputs
Ahn, Min [2014]	Selected 23 international airports	Land area Length of runway Passenger terminal area Cargo terminal area	Number of passengers Number of aircraft movements Tonnes of cargo carried
Pedram, Payan [2015]	7 Iran airports	Number of employees Domestic terminal area External terminal area Number of terminals	Number of aircraft movements Passenger movements Cargo handled
Wilbert et al. [2017]	63 Brazilian airports	Total costs	Revenue from unregulated activities Revenue from regulated activities Number of passengers Air cargo and postal mail handling
Asker, Battal [2017]	Selected 20 international airports	Number of runways Number of aircraft Number of gates Terminal area size	Total number of passengers Total number of flights Total freight
Fernandes, Pacheco [2018]	60 Brazilian airports	Average number of employees Payroll, including direct and indirect benefits operating expenses	Total passengers, embarked plus disembarked Freight plus mail, embarked plus disembarked Operating revenue Commercial revenue
Stichhauerova, Pelloneova [2019]	27 German airports	Number of employees Number of terminals Number of runways Airport area Capacity Distance from the city centre	Number of passengers Number of aircraft movements Amount of cargo

Source: Authors' own elaboration.

Wang et al. [2004] used Grey relation analysis and the TOPSIS method for the performance evaluation of major airports in Taiwan. In the study, 10 airports were evaluated and ranked according to four criteria. Aydoğan [2011] used rough-AHP and fuzzy TOPSIS methods for the performance measurement of aviation companies in Turkey. In the study, four aviation firms were evaluated according to five criteria. In the study, the weights of the criteria were determined with the rough-AHP method, and the performance evaluation and ranking of the companies were carried out with the TOPSIS method.

Eshtaiwi et al. [2017] used the Grey system theory to assess airport performance in Libya. In the study, three international airports were evaluated according to economic/financial, service quality, environmental impact, airside efficiency, safety and security criteria. As a result of the study, three airports were ranked. Ghorabae et al. [2017] used the EDAS, TOPSIS, COPRAS and WASPAS methods to evaluate the service quality performance of airlines. In the study, five airlines were evaluated according to tangibles responsiveness,

empathy, flight pattern, reliability and assurance criteria. Five airline companies were ranked according to the results of four different methods.

Perçin and Aldolou [2018] used the fuzzy AHP and fuzzy TOPSIS methods to evaluate airlines in Turkey. In the study, criterion weights were determined using the fuzzy AHP method and alternatives were listed with the fuzzy TOPSIS method. Wang and Pham [2019] used the entropy-based TOPSIS method to evaluate the domestic ground handling performance of 17 airports in Vietnam in 2017. First, the weights of check-in, boarding, check-in queue time, staff attitude, baggage, safety and on-time performance criteria were determined using the entropy method. In the second step, the performance evaluation of 17 airports was carried out using the TOPSIS method according to seven criteria. In the last stage of the study, the airports were ranked.

There are studies in the literature in which the DEA method is used together with MCDM methods [Lotfi et al., 2011; Çelen, Yalçın, 2012; Babae et al., 2015; Fan et al., 2019; Lee et al., 2020; Ersoy, Dogan, 2020; Ersoy, 2021]. Some of the studies in which performance evaluation was carried out in the aviation industry using the DEA and MCDM methods together were given in the following paragraphs.

Lai et al. [2015] used the AHP and DEA methods to evaluate the performance of 24 major international airports. In the study, the number of employees, number of runways, operating expenditure, size of terminal area, number of gates, and length of runway were used as input variables, while total revenue, amount of freight and mail, number of aircraft movements, and number of passengers were used as output variables. The results of the DEA and AHP methods were compared and the airports were ranked.

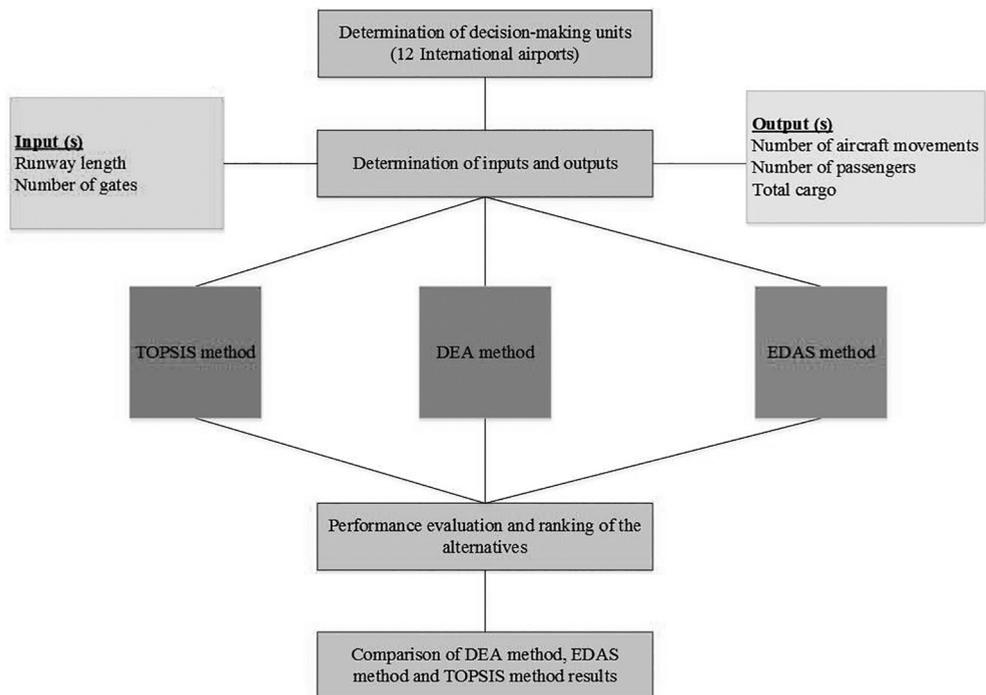
Keskin and Köksal [2019] used the DEA and AHP methods to evaluate the performance of 48 public airports in Turkey. In the study, the number of gates, number of employees, runways area, operational expenditure, and terminal area were used as inputs, while the number of passengers, amount cargo, aircraft movements and total revenue were used as outputs. DMUs were ranked by comparing the results of the DEA and AHP methods.

## Methodology

In this study, the performance of 12 major international airports has been evaluated using the DEA, EDAS and TOPSIS methods. Although the DEA method is useful, it has some important limitations. One important disadvantage of the DEA method is that the DMUs cannot be fully ranked. However, it is believed that MCDM methods will be combined with DEA for the full ranking of DMUs. According to some authors, it is argued that the DEA method is an MCDM method [Somogyi 2011; Azadfallah, 2018]. Although the DEA method is recommended for evaluating the efficiency score of DMUs, it is thought to play a wide role as an MCDM tool. In the literature, different ways of using the DEA method as an MCDM approach have been proposed

[Mousavi-Nasab, Sotoudeh-Anvari, 2017]. In the classical DEA method, it is difficult to rank efficient DMUs either among themselves or in relation to inefficient DMUs. Therefore, a fully and efficient ranking can be made by applying DEA methods together with the (Super Efficiency) SE-DEA model and MCDM methods. First, input and output variables as well as the DMUs of the study were determined. Later, the performance of airports, which are DMUs, was evaluated according to three different methods. The framework of the study can be seen in Figure 1. The DEA, EDAS, TOPSIS methods, data and variables of the study are explained below.

Figure 1. The framework of the study



Source: Authors' own elaboration.

## DEA Method

DEA is a method used to evaluate the performance of a set of peer entities called the decision-making unit. In recent years, DEA has had a wide range of applications in different fields and countries [Cooper et al., 2011]. The first DEA model presented by Charnes, Cooper and Rhodes [1978] was based on Farrell's [1957] previous studies. Charnes, Cooper and Rhodes paid attention to Farrell's article "The Measurement of Productive Efficiency", in the 1957 Journal of the Royal Statistical Society. In this article, Farrell used "activity analysis concepts" [Cooper et al., 2011].

Charnes, Cooper and Rhodes [1978] conducted their first studies on DEA with the article entitled “Measuring the Efficiency of Decision Making Units” [Charnes et al., 1978]. DEA is a non-parametric method. There are different versions of DEA depending on its features. These are Constant Return Scale (CRS) and Variable Return Scale (VRS). The CRS version was created by Charnes, Cooper and Rhodes [1978] and called the CCR model. The VRS version was created by Banker, Charnes and Cooper [1984] and called the BCC model. In the CCR model, an increase in the amount of input is assumed to result in a proportional increase in the amount of output. In the BCC model, the amount of output increases more or less than the amount of input [Dalfard et al., 2012]. In the DEA method, the relative efficiency of DMUs is compared among themselves [Ersoy, 2021].

The main reason for the extensive use of DEA is that it enables analysis in multiple input and multiple output environments [Charles, Kumar, 2012; Ersoy, 2021]. The selection of DMUs with similar characteristics makes sure that the number of DMUs is twice the total number of inputs and outputs [Bousofiane et al., 1991; Altın, 2014; Yoshimoto et al., 2018; Ersoy, 2021].

The input-oriented CCR model and input-oriented SE-CCR model were used in the study. The efficiency score of efficient DMUs in the CCR model is 100%, that is “1”. The SE-CCR model can be useful in ranking efficient DMUs. The input-oriented CCR model (1) [Cooper et al., 2011; Xu, Ouenniche, 2012; Ersoy, 2021] and the input-oriented SE-CCR model (2) [Seiford, Zhu, 1999; Xu, Ouenniche, 2012; Ersoy, 2021] can be seen in Table 2.

**Table 2. Input-oriented CCR model and input-oriented SE-CCR model**

CCR Model	SE-CCR Model
$\min \theta_t$ <p>s.t.</p> $\sum_{j=1}^n \lambda_j x_{ij} \leq \theta_t x_{it}, \quad i = 1, \dots, m$ $\sum_{j=1}^n \lambda_j y_{rj} \geq y_{rt}, \quad r = 1, \dots, s$ $\lambda_j \geq 0, \quad j = 1, \dots, n$	$\min \theta_t$ <p>s.t.</p> $\sum_{j=1}^n \lambda_j x_{ij} \leq \theta_t x_{it}, \quad i = 1, \dots, m$ $\sum_{j=1}^n \lambda_j y_{rj} \geq y_{rt}, \quad r = 1, \dots, s$ $\lambda_j \geq 0, \quad j = 1, \dots, n$

Source: Authors' own elaboration.

In model (1) and model (2),  $x_{ij}$  denotes the amount of input  $i$  used by  $DMU_j$  and  $y_{rj}$  denotes the amount of output  $r$  produced by  $DMU_j$  [Xu, Quenniche, 2012]. In model (1),  $j = 1, \dots, n$  and  $\theta_t$  refers to  $DMU_t$  whose efficiency is measured. If the optimal value of  $\theta_t$  is equal to 1, then  $DMU_t$  under evaluation is efficient; else,  $\theta_t < 1$  indicates that  $DMU_t$  is inefficient. In model (2),  $\theta_t < 1$  indicates that  $DMU_t$  is inefficient; else, efficient  $DMU_s$  will have a  $\theta_t \geq 1$  [Xu, Quenniche, 2012; Ersoy, 2021].

## TOPSIS Method

The TOPSIS method was first developed by Hwang and Yoon in 1981 [Hwang, Yoon, 1981; Chen, 2000; Ersoy, 2021]. The method is based on the principle of identifying the distances of the alternatives subjected to evaluation from the positive ideal solution and negative ideal solution [Chen, 2000; Rouyendegh et al., 2018; Ersoy, 2021]. The steps of the TOPSIS method as follows [Hwang, Yoon, 1981; Shih et al., 2007; Chitnis, Vaidya, 2016; You et al., 2017; Rouyendegh et al., 2018; Ersoy, 2021].

*Step 1: Creating the decision matrix.*

There are  $i, i = 1, 2, \dots, m$  alternatives in the rows of the decision matrix  $A_{ij}$  and  $j, j = 1, 2, \dots, n$  criteria in the columns. The decision matrix is shown below.

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (3)$$

*Step 2: Creating the normalised decision matrix.*

The normalised decision matrix is calculated using equation (4).

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (4)$$

the normalised decision matrix is shown below.

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

*Step 3: Creating the weighted normalised decision matrix.*

First, the weight values ( $w_j$ ) for the evaluation criteria are determined. Then the weighted normalised decision matrix is created by multiplying the elements in each column of the matrix by the corresponding value of  $w_j$ . The weighted normalised value  $y_{ij}$  is obtained as in equation (5).

$$y_{ij} = w_j \cdot r_{ij} \quad (5)$$

the weighted normalised decision matrix is shown below.

$$Y_{ij} = \begin{bmatrix} w_1 r_{11} & w_1 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix} \tag{6}$$

where  $y_{ij}$  is the weighted normalised value of the  $j$ th criterion of the  $i$ th alternative

*Step 4:* Creating a positive ideal set ( $A^*$ ) and negative ideal set ( $A^-$ ).

To create the ideal solution set, the largest of the weighted column values in  $Y_{ij}$  matrix is chosen. The positive ideal solution set is obtained from equation (7).

$$A^* = \{(\max_i y_{ij} | j \in J), (\min_i y_{ij} | j \in J')\} \tag{7}$$

The negative ideal solution set is created by choosing the smallest of the weighted column values in  $Y_{ij}$  matrix. The negative ideal solution set is obtained from equation (8).

$$A^- = \{(\min_i y_{ij} | j \in J), (\max_i y_{ij} | j \in J')\} \tag{8}$$

In both equations,  $J$  benefit and  $J'$  loss value, where  $y_j^*$  represents the positive ideal solution of the  $j$ th criterion;  $y_j^-$  represents the negative ideal solution

*Step 5:* Calculating the distance of each alternative to the positive ideal solution and the negative ideal solution.

The distance to the positive ideal solution is  $S_i^*$  and the distance to the negative ideal solution is  $S_i^-$ . The distance to the positive ideal solution is calculated using equation (9) and the distance to the negative ideal solution is calculated using equation (10).

$$S^* = \sqrt{\sum_{j=1}^n (y_{ij} - y_j^*)^2} \tag{9}$$

$$S^- = \sqrt{\sum_{j=1}^n (y_{ij} - y_j^-)^2} \tag{10}$$

*Step 6:* Compute the relative proximity of each alternative to the ideal solution.

The relative closeness ( $C_i^*$ ) of each alternative to the ideal solution is calculated as in equation (11).

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (11)$$

where  $0 \leq C_i^* \leq 1$ .

### EDAS Method

The EDAS method was first developed by Keshavarz Ghorabae et al. [2015]. In this method, the average solution is used to evaluate the alternatives. The positive distance average (PDA) and negative distance average (NDA) are two separate measures used to evaluate alternatives. The best alternative is chosen based on these two distances [Ghorabae et al., 2015; Kahraman et al., 2017; Chatterjee et al., 2018; Adalı, Tuş, 2019]. The steps of the EDAS method were given below [Ghorabae et al., 2015; Stanujkic et al., 2017; Chatterjee et al., 2018; Aggarwall et al., 2018; Adalı, Tuş, 2019]:

*Step 1:* Choosing alternatives and criteria and creating a decision matrix (X).

$$X = [x_{ij}]_{n \times m} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (12)$$

where  $x_{ij}$  demonstrates the performance value of  $i$  th alternative on  $j$  th criterion.

*Step 2:* Determine the average solution considering all criteria.

$$AV = [AV_j]_{1 \times m} \quad (13)$$

where

$$AV_j = \frac{\sum_{i=1}^m x_{ij}}{m} \quad (14)$$

*Step 3:* Calculate the positive distance from average (PDA) and the negative distance from average (NDA) matrices according to the type of criteria (cost and benefit).

$$PDA = [PDA_{ij}]_{n \times m} \quad (15)$$

$$NDA = [NDA_{ij}]_{n \times m} \quad (16)$$

If  $j$  th criterion is beneficial,

$$PDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \quad (17)$$

$$NDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \quad (18)$$

and if the  $j$  th criterion is non-beneficial

$$PDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \quad (19)$$

$$NDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \quad (20)$$

where  $PDA_{ij}$  and  $NDA_{ij}$  demonstrate the positive and negative distance of  $i$  th alternative from the average solution in terms of the  $j$  th criterion respectively.

*Step 4:* Calculate the weighted sum of  $PDA$  and the weighted sum of  $NDA$  for all alternatives.

$$SP_i = \sum_{j=1}^m w_j PDA_{ij} \quad (21)$$

$$SN_i = \sum_{j=1}^m w_j NDA_{ij} \quad (22)$$

where  $w_j$  is the weight of the  $j$  th criterion.

*Step 5:* Normalise the  $SP$  and  $SN$  values for all alternatives.

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \quad (23)$$

$$NSN_i = 1 - \frac{SN_i}{\max_i(SN_i)} \quad (24)$$

*Step 6:* Calculate the appraisal score (AS) for all alternatives.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \quad (25)$$

where  $0 \leq AS_i \leq 1$

*Step 7:* Ranking of the alternatives considering the descending values of AS. The alternative with the biggest AS value is the best.

## Data Collection and Variables

The data set of the study was obtained from the website of the ACI, the website of the airports and other websites [URL1-URL40, 2021]. The ACI announced on its website the top 20 airports for cargo, passenger traffic and aircraft movements in 2019 and the first quarter of 2020. Overall, the data of 20 major international airports decreased in the first quarter of 2020

compared to the first quarter of 2019 [URL 1 and URL5, 2021]. Twelve international airports whose data were available and suitable for analysis were included in the study. The input and output variables used in the study were determined based on the literature review in Table 1 and other studies [Lai et al., 2015; Keskin, Köksal, 2019]. The input and outputs used in the DEA method were also used in the TOPSIS and EDAS methods. The descriptions for the input and outputs variables of the research can be seen in Table 3. In this study, 12 major international airports were selected as DMUs. That was enough to conduct a reliable DEA analysis [Ersoy, 2021]. The descriptive statistics of inputs and outputs used in the study are given in Table 4.

**Table 3. The description of input and output variables**

Variable	Explanation	Units
<b>Input (s)</b>		
Runway length	Length of total runways at airport	Metre
Number of gates	Number of boarding gates at airport	Unit
<b>Output (s)</b>		
Number of aircraft movements	Total number of flights landing and taking off from airport	Unit
Number of passengers	Total number of incoming and outgoing passengers at airport	Unit
Total cargo	Total amount of freight and mail	Tonne

Source: Authors' own elaboration.

**Table 4. Descriptive statistics for input and output variables**

	Year	2019	Q1 2020
<b>Input (s)</b>			
Runway length	Maximum	19467	19467
	Minimum	7560	7560
	Total	160029	160029
	Mean	13336	13336
	Standard deviation	4284	4284
Number of gates	Maximum	223	223
	Minimum	91	91
	Total	1764	1764
	Mean	147	147
	Standard deviation	34,7	34,7
<b>Output (s)</b>			
Number of aircraft movements	Maximum	919704	205675
	Minimum	373261	63330
	Total	6395946	1189249
	Mean	532996	99104
	Standard deviation	148232	41208

	Year	2019	Q1 2020
Number of passengers	Maximum	100011438	17823446
	Minimum	70556072	8077491
	Total	950585714	143881514
	Mean	79215476	11990126
	Standard deviation	9064788	3285131
Total cargo	Maximum	4809485	988000
	Minimum	1592221	301449
	Total	28911191	6040445
	Mean	2409266	503370
	Standard deviation	942441	203921

Source: Authors' own elaboration.

## Results and Discussion

In the first phase of the study, the performance of 12 major international airports was evaluated according to the DEA, EDAS and TOPSIS methods using two input and three output variables. In the last phase of the study, the airports were ranked according to the results of all three methods. The results and comparisons of the models used in the study follow.

### DEA Method Results

The efficiency analysis conducted in the study used the CCR-DEA and SE-CCR-DEA models. It was carried out with E.M.S. 1.3.0 software using 12 DMUs, two inputs and three output variables. The results of the DEA analysis can be seen in Table 5.

**Table 5. Efficiency scores of the airports in 2019 and Q1 2020**

DMUs	Airports	2019				Q1 2020			
		CCR %	Rank	SE-CCR %	Rank	CCR %	Rank	SE-CCR %	Rank
A <sub>1</sub>	Beijing Capital International Airport	100.0	1	107.44	4	56.9	11	56.87	11
A <sub>2</sub>	Los Angeles International Airport	100.0	1	107.37	5	100.0	1	125.22	3
A <sub>3</sub>	Dubai International Airport	100.0	1	104.98	6	100.0	1	127.98	2
A <sub>4</sub>	Chicago O'Hare International Airport	92.9	8	92.93	8	93.7	6	93.7	6
A <sub>5</sub>	London Heathrow International Airport	100.0	1	115.67	3	100.0	1	123.23	4
A <sub>6</sub>	Shanghai Pudong International Airport	84.0	9	84.04	9	76.1	8	76.14	8

DMUs	Airports	2019				Q1 2020			
		CCR %	Rank	SE-CCR %	Rank	CCR %	Rank	SE-CCR %	Rank
A <sub>7</sub>	Paris Charles de Gaulle International Airport	72.7	10	72.7	10	72.7	9	72.72	9
A <sub>8</sub>	Guangzhou Baiyun International Airport	100.0	1	118.89	2	85.7	7	85.7	7
A <sub>9</sub>	Amsterdam Schiphol International Airport	49.2	12	49.18	12	45.9	12	45.86	12
A <sub>10</sub>	Hongkong International Airport	100.0	1	212.63	1	100.0	1	193.35	1
A <sub>11</sub>	Frankfurt International Airport	72.1	11	72.11	11	71.6	10	71.58	10
A <sub>12</sub>	Seoul Incheon International Airport	98.7	7	98.69	7	100.0	1	113.13	5
	<b>Mean</b>	<b>89.1</b>		<b>103.5</b>		<b>83.6</b>		<b>98.79</b>	

Source: Authors' own elaboration.

The efficiency scores of the airports were expressed in percentage terms (%) in Table 5. The airports, which are DMUs, are listed in the first column of Table 5, from A<sub>1</sub> to A<sub>12</sub> respectively. Six airports were efficient in 2019 and five airports were efficient in Q1 2020 according to the CCR model. The airports that are efficient according to the CCR models in Table 5 are also efficient according to the SE-CCR model. The efficiency score of the efficient airports is 100% in Table 5. In 2019, the average efficiency score was 89.1% according to the CCR DEA. The airport with the lowest efficiency score in 2019 and Q1 2020 was Amsterdam Schiphol International Airport.

According to the results of the DEA method, it can be seen that the efficiency scores of A<sub>1</sub>, A<sub>6</sub> and A<sub>8</sub> decreased in the first quarter of 2020. It is possible to say that the decrease in the efficiency of these airports in China was directly related to COVID-19.

The results of the CCR-DEA analysis allows us to identify efficient and inefficient airports. The CCR-DEA method allows the inefficient airports to be ranked among themselves and in relation to efficient airports. However, it is necessary to rank the efficient airports in relation to each other and with regard to the inefficient airports. The SE-CCR model is useful to rank efficient airports. The TOPSIS and EDAS methods are MCDM methods used as an alternative for rankings where the DEA method is insufficient.

It should be remembered that the efficiency measurement performed with the DEA method is relative. For this reason, if the DMUs change, the efficiency results will also change. As input-oriented models are used in the analysis, the outputs should be kept constant and the inputs should be reduced for the inefficient airports to be efficient. It is understood that inefficient airports do not use inputs efficiently and create excessive inputs.

## EDAS Method Results

In the study, the EDAS and TOPSIS methods were applied using Microsoft Excel 2016 software and the same inputs and outputs as those used in the DEA. The weights of the criteria used in the TOPSIS and EDAS methods were taken into account equally [Mehdiabadi et al., 2013; Chitnis, Vaidya, 2016; Fan et al., 2019; Ersoy, 2021]. The results of the EDAS method can be seen in Table 6.

**Table 6. EDAS method results of the airports in 2019 and Q1 2020**

Airports	2019						Q1 2020					
	$SP_i$	$SN_i$	$NSP_i$	$NSN_i$	$AS_i$	Rank	$SP_i$	$SN_i$	$NSP_i$	$NSN_i$	$AS_i$	Rank
Beijing Capital Int. A.	0.12	0.04	0.44	0.87	0.653	2	0.05	0.18	0.18	0.30	0.240	11
Los Angeles Int.A.	0.10	0.03	0.35	0.91	0.630	3	0.19	0.02	0.69	0.93	0.810	2
Dubai Int. A.	0.12	0.06	0.41	0.79	0.600	4	0.21	0.04	0.76	0.86	0.811	1
Chicago O'Hare Int. A.	0.16	0.20	0.56	0.30	0.430	9	0.26	0.19	0.94	0.26	0.601	5
London Heathrow Int. A.	0.11	0.08	0.39	0.72	0.551	6	0.15	0.06	0.54	0.76	0.653	4
Shanghai Pudong Int. A.	0.10	0.11	0.36	0.61	0.484	7	0.10	0.21	0.34	0.16	0.251	10
Paris Charles de Gaulle Int. A.	0.00	0.06	0.01	0.79	0.402	10	0.02	0.05	0.08	0.79	0.434	7
Guangzhou Baiyun Int. A.	0.11	0.07	0.38	0.75	0.567	5	0.11	0.17	0.39	0.33	0.357	9
Amsterdam Schiphol Int. A.	0.00	0.29	0.00	0.00	0.000	12	0.01	0.25	0.04	0.00	0.018	12
Hongkong Int. A.	0.29	0.08	1.00	0.73	0.866	1	0.28	0.15	1.00	0.41	0.704	3
Frankfurt Int. A.	0.00	0.08	0.01	0.73	0.371	11	0.00	0.06	0.01	0.75	0.381	8
Seoul Incheon Int. A.	0.08	0.10	0.28	0.66	0.469	8	0.11	0.11	0.41	0.57	0.486	6
<b>Mean</b>	<b>0.10</b>	<b>0.10</b>	<b>0.35</b>	<b>0.66</b>	<b>0.50</b>		<b>0.12</b>	<b>0.12</b>	<b>0.45</b>	<b>0.51</b>	<b>0.48</b>	

Source: Authors' own elaboration.

Table 6 shows that Amsterdam Schiphol International Airport was the airport with the lowest  $AS_i$  value in 2019, while Hongkong International Airport was the airport with the highest  $AS_i$  value. In 2019, their average values  $AS_i$  were 0.5, while their average values in Q1 2020 were 0.48. According to the EDAS method results, Dubai International Airport ranked first in Q1 2020, while Amsterdam Schiphol International Airport ranked last. Meanwhile, a general evaluation made with the EDAS method reveals that the  $AS_i$  values of international airports in China, where COVID-19 was first seen, decreased in Q1 2020.

## TOPSIS Method Results

Twelve international airports have been evaluated according to the TOPSIS method. The TOPSIS method results and airport rankings can be seen in Table 7.

**Table 7. TOPSIS method results for the airports in 2019 and Q1 2020**

Airports	2019				Q1 2020			
	$S_i^*$	$S_i^-$	$C_i^*$	Rank	$S_i^*$	$S_i^-$	$C_i^*$	Rank
Beijing Capital International Airport	0.076	0.058	0.434	5	0.112	0.049	0.303	11
Los Angeles International Airport	0.072	0.057	0.441	3	0.070	0.076	0.521	1
Dubai International Airport	0.079	0.061	0.436	4	0.083	0.079	0.487	5
Chicago O'Hare International Airport	0.093	0.059	0.391	9	0.089	0.085	0.488	4
London Heathrow International Airport	0.069	0.063	0.478	2	0.075	0.077	0.508	2
Shanghai Pudong International Airport	0.075	0.054	0.419	7	0.103	0.053	0.340	9
Paris Charles de Gaulle International Airport	0.085	0.041	0.329	10	0.095	0.049	0.342	8
Guangzhou Baiyun International Airport	0.082	0.063	0.432	6	0.109	0.062	0.361	7
Amsterdam Schiphol International Airport	0.111	0.015	0.118	12	0.116	0.029	0.201	12
Hongkong International Airport	0.062	0.091	0.595	1	0.093	0.092	0.497	3
Frankfurt International Airport	0.085	0.040	0.319	11	0.095	0.045	0.321	10
Seoul Incheon International Airport	0.081	0.053	0.398	8	0.093	0.062	0.398	6
<b>Mean</b>	<b>0.081</b>	<b>0.055</b>	<b>0.399</b>		<b>0.094</b>	<b>0.063</b>	<b>0.397</b>	

Source: Authors' own elaboration.

In the first column of Table 7, there are alternatives, namely international airports. According to the TOPSIS method results, Amsterdam Schiphol International Airport was the alternative with the lowest  $C_i^*$  value in 2019, while Hongkong International Airport was the alternative with the highest  $C_i^*$  value.

The  $C_i^*$  values of airports in China decreased in Q1 2020. According to Table 7, Los Angeles International Airport ranked first in Q1 2020. The average value of  $C_i^*$  in 2019 was 0.399, decreasing to 0.397 in Q1 2020. London Heathrow International Airport was in second place in the first quarter of 2019 and Q1 2020, while Amsterdam Schiphol International Airport was in 12th place.

## Discussion

The comparison of the CCR, SE-CCR, EDAS and TOPSIS methods and the rankings of the airports can be seen in Table 8. Besides, the correlation between the results of the three methods was examined with the Spearman Correlation approach and the correlation results are given in Table 9.

**Table 8. Ranking of airports according to CCR, SE-CCR, EDAS and TOPSIS methods**

Airports	2019				Q1 2020			
	CCR	SE-CCR	EDAS	TOPSIS	CCR	SE-CCR	EDAS	TOPSIS
Beijing Capital International Airport	1	4	2	5	11	11	11	11
Los Angeles International Airport	1	5	3	3	1	3	2	1
Dubai International Airport	1	6	4	4	1	2	1	5
Chicago O'Hare International Airport	8	8	9	9	6	6	5	4
London Heathrow International Airport	1	3	6	2	1	4	4	2
Shanghai Pudong International Airport	9	9	7	7	8	8	10	9
Paris Charles de Gaulle International Airport	10	10	10	10	9	9	7	8
Guangzhou Baiyun International Airport	1	2	5	6	7	7	9	7
Amsterdam Schiphol International Airport	12	12	12	12	12	12	12	12
Hongkong International Airport	1	1	1	1	1	1	3	3
Frankfurt International Airport	11	11	11	11	10	10	8	10
Seoul Incheon International Airport	7	7	8	8	1	5	6	6

Source: Authors' own elaboration.

As can be seen from Table 8, Hongkong International Airport ranks first in all methods in 2019. According to the results in Table 8, it is possible to say that the ranking made using the CCR-DEA and SE-CCR-DEA models and the EDAS and TOPSIS methods for airports is more advantageous than using only the CCR-DEA model. Thus, it is possible to see the ranking of efficient airports according to the DEA models among themselves and in relation to the inefficient airports. In cases where the DEA method is insufficient, it can be said that the combination of the DEA method and MCDM methods ensures the full ranking of alternatives.

As can be seen from the general assessment of Table 8, the ranking of international airports in China decreased in Q1 2020. Also, the performance ranking of Frankfurt International Airport and Paris Charles de Gaulle International Airport increased in Q1 2020. This can be explained by the direct negative impact of COVID-19 on the airports in China and the low negative impact of COVID-19 in Europe in Q1 2020. Tables 5, 6 and 7 show that the average performance evaluation results for the 12 airports in all three methods decreased numerically in Q1 2020 compared to 2019.

**Table 9. Spearman's correlation coefficient between the methods and the performance results**

Correlations			2019				Q1 2020			
			CCR	SE-CCR	EDAS	TOPSIS	CCR	SE-CCR	EDAS	TOPSIS
Spearman's rho	CCR	Correlation Coefficient	1.000	.937**	.914**	.914**	1.000	.964**	.885**	.914**
		Sig. (2-tailed)	.	.000	.000	.000	.	.000	.000	.000
		N	12	12	12	12	12	12	12	12
	SE-CCR	Correlation Coefficient	.937**	1.000	.874**	.888**	.964**	1.000	.916**	.902**
		Sig. (2-tailed)	.000	.	.000	.000	.000	.	.001	.000
		N	12	12	12	12	12	12	12	12
	EDAS	Correlation Coefficient	.914**	.874**	1.000	.909**	.885**	.916**	1.000	.888**
		Sig. (2-tailed)	.000	.000	.	.000	.000	.000	.	.000
		N	12	12	12	12	12	12	12	12
	TOPSIS	Correlation Coefficient	.914**	.888**	.909**	1.000	.914**	.902**	.888**	1.000
		Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.
		N	12	12	12	12	12	12	12	12

\*\* . Correlation is significant at the 0.01 level (2-tailed).

Source: Author's one elaboration.

Table 9 shows that there is a strong positive relationship between the methods used and the results obtained. Also, it can be said that the DEA method used in the study is consistent with the EDAS and TOPSIS methods and all correlation coefficients are greater than 0.7.

Another important aspect is to keep in mind that the results of the study were based on the existing data set. The models used in the study were input-oriented DEA models. With some improvements in inputs and keeping the outputs constant, inefficient airports may become efficient. Similarly, when Chicago O'Hare International Airport's "number of gates" variable is decreased by approximately 9.4%, it will rise to eighth place according to the TOPSIS method in 2019 and remain in ninth place according to the EDAS method. According to the TOPSIS method, it will move up from fourth to third place and remain in fifth place according to the EDAS method in Q1 2020.

## Conclusion

With the developments in globalisation and transportation technology, airports need to constantly evaluate their performance in an intensely competitive environment. The main purpose of airport managers is to use the available resources as efficiently as possible. When the literature is examined

in measuring the efficiency of airports, it can be seen that the DEA method is widely used.

As in many other sectors, performance evaluation of airports in the aviation industry is important in terms of sustainability and competition. For this purpose, the performance and rankings of 12 selected major international airports have been evaluated using the DEA, EDAS and TOPSIS methods.

As a result of the DEA models used, six airports were found to be efficient in 2019, and five airports were found to be efficient in Q1 2020. All the airports that were efficient in the CCR-DEA model in 2019 and Q1 2020 were also efficient in the SE-CCR-DEA model.

The TOPSIS and EDAS methods used the same inputs and outputs and DMUs as those used in the DEA method. According to the results of the CCR-DEA and SE-CCR-DEA models and the EDAS and TOPSIS methods, Hong-kong International Airport ranked first in 2019. According to all three methods, Paris Charles de Gaulle International Airport was in 10th place, Frankfurt International Airport was ranked 11<sup>th</sup>, and Amsterdam Schiphol International Airport was in 12th place in 2019. In Q1 2020, Beijing Capital International Airport was ranked 11th according to all three methods. Amsterdam Schiphol International Airport ranked 12th in both 2019 and Q1 2020 according to the DEA, EDAS and TOPSIS method results.

If some improvements were made in the inputs used in the study (including runway length and the number of gates) the inefficient airports would be enabled to become efficient. Since the DEA models used in the study were input-oriented, inefficient airports could become efficient with some improvements in input variables by keeping output variables constant. In the study, it was concluded that if the “number of gates” variable of Chicago O’Hare International Airport decreased by approximately 9.4%, the airport would be efficient in the DEA models and there would be improvements in its ranking obtained with the TOPSIS and EDAS methods.

The aviation industry, like many other industries worldwide, has been adversely affected by the COVID-19 outbreak. There have been decreases in the number of passengers and number of aircraft movements, and it is predicted that this downward trend will continue. Many stakeholders in the aviation industry, such as airports, airlines, employees, suppliers, ticket sales offices and tourism agencies as well as catering and cleaning companies have been negatively affected by COVID-19. Airports have faced difficulties in meeting many fixed expenses such as personnel, heating, electricity and cleaning due to decreased incomes. These negative developments in the aviation industry, which is an important industry in the world economy, have had an indirect effect on many other sectors.

It is not known exactly when the COVID-19 epidemic will end, what kind of impact it will have, and whether there will be new epidemics. In this uncertain environment, airports and other companies in the aviation industry need to develop scenarios assuming that the COVID-19 outbreak will continue or that there may be new outbreaks. It will be beneficial for airports to seek

methods to combat epidemics such as COVID-19 and to provide cost control to be successful in the sector and to ensure their sustainability. They need to develop product and marketing strategies accordingly.

Inefficient airports in the research should draw from the experience of efficient airports. Airport officials can come together with authorised public institutions and private sector representatives and act together to make their airport efficient. Another possible solution for airport managers would be to use technologies such as artificial intelligence, big data, machine learning, cloud computing and the Internet of Things, which are components of Industry 4.0. Using these technologies, they can switch to the smart airport concept. They can check the health status of passengers and create automatic transit points, quarantine zones and sterile zones at airports. They can make flight plans according to the health status of the passengers (such as risky, low risk and no risk), and evaluate passengers with similar health conditions in the same group. On the other hand, it may be beneficial to carry out marketing and promotional activities to inform customers that aviation sector employees, especially airport and airline employees, regularly undergo health checks and that airports and airline vehicles are constantly under virus control.

Like any scientific study, this study has some limitations. It should be remembered that relative efficiency was measured with the DEA method. DEA is one of the most widely used methods of efficiency measurement and has many advantages compared to alternative methods. The use of the input-oriented DEA model and the fact that the efficiency analysis was carried out with two inputs and three outputs are some of the limitations of the study. Another limitation of the study is that the efficiency analysis is limited to 12 major international airports. A further limitation is that the study was conducted using data between 2019 and Q1 2020. Using only two MCDM methods in addition to the DEA method is yet another limitation of the study.

This study was carried out to evaluate the performance of 12 major airports. In the future, studies of airports in different countries can be carried out. Different performance evaluation studies can be carried out by including new inputs and/or outputs. The EDAS and TOPSIS methods were used together with the DEA method in this study. Also, the performance of airports or other sectors can be evaluated using DEA and other MCDM methods together in future studies. Another research topic may be to re-evaluate the impact of the COVID-19 epidemic on airports and the aviation industry using data from 2020 and 2021 or when the COVID-19 epidemic is over.

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