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Measurement of Process-Performances of Turkish Airports Using Network Data Envelopment Analysis

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Abstract

The air transportation industry is continuously broadening by adding new airports operating with huge investments. Hence, increasing efficiency and productivity in this industry is becoming critical. At the same time, efficiency calculations are also an important tool used to identify weaknesses and contribute to the improvement of the performance of enterprises. Nevertheless, Classic DEA models are commonly insufficient to determine the efficiency of a system due to ignorance of its internal structure and the treatment of the system as a black box. Therefore, if a production system can be divided into subprocesses by using network DEA model, the results will be more plausible and satisfying. Within this scope, this paper aims to evaluate the efficiencies of 39 out of 56 airports in Türkiye from 2015 to 2019. The results indicate that less-populated airports managed by private entrepreneurs are more efficient than others. Moreover, another characteristic of these efficient airports is that they are both domestically and internationally preferred for leisure trips.

1. Introduction

Globalization has increased economic activity all around the world. This was implemented first by preferring road transport, then sea transport, and finally air transport. The development of technology has provided a contribution to change this preference. All these developments have contributed to the rapid growth of the industry in Türkiye, as in many other countries. However, significant developments in passenger and freight transportation have been recorded in the transportation sector. In addition, the development of industrialization, population growth, and urbanization contribute to the increase in economic activities and make it easier for people to travel for touristic purposes. All these factors allow for the steady development of transport demand. In this progression, the preference for air travel for traveling to nearby or distant countries in personal or group leisure and business travel has a share.

The deregulation process of the aviation industry has led both airlines and airports into a more competitive and dynamic market. This movement started in America and then expanded to other countries. Before COVID-19, the global air transport industry contributed 4.1% of worldwide GDP in revenue and supported over 85 million worldwide jobs (ATAG, 2020). In the last five years, the air transport industry has contributed an average of 7 percent of revenue to Türkiye's GDP (TUIK, 2020). This acceleration was provided by completing the deregulation of Türkiye's air transport industry, which was started in the 1980s. After 2003, Türkiye's aviation industry, especially passenger and cargo transportation as shown in Figure-1. Cargo traffic is primarily based on Istanbul airports. Passenger traffic is also influenced by dense economic activity and tourist destinations.

The Directorate-General of the State Airports Enterprise (DHMI) is the authority to enforce the rules, manage and control the Turkish airports, which are 56 (green-point in Figure-2) as of 2021. Figure-2 shows the actual active commercial airports in Türkiye. Most of them are being managed by the public authority (DHMI), some of them (such as Istanbul, Ankara, İzmir, Antalya, Alanya, Bodrum, Dalaman) are being managed by private entrepreneurs.

The air transport sector is constantly expanding with new airports (Bloomberg, 2021). Therefore, governments are always trying to develop policies to improve the efficiency of airport operations. The quantitative description of efficiency is a comparison of the inputs used and the outputs realized. They use some methodologies to rate performance in air transport to help public authorities determine whether some airports can be considered more efficient than others (Stichhauerova & Pelloneova, 2019).

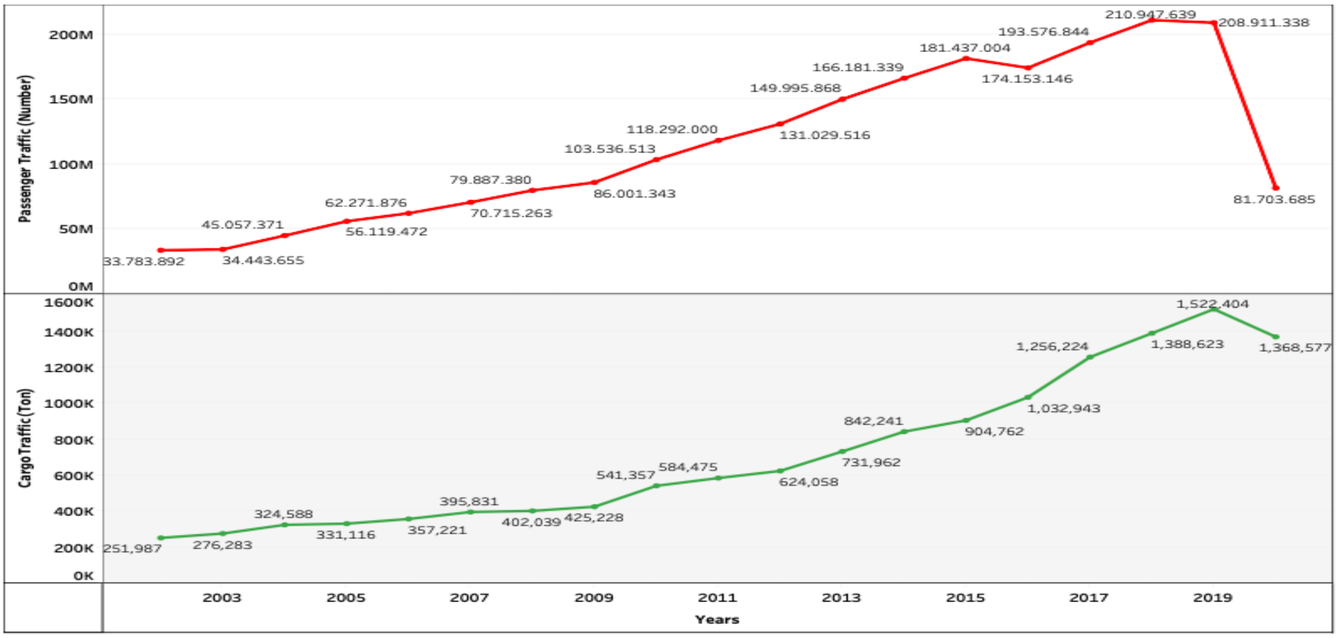

Figure 1. Turkish Airports Total Traffic (DHMI, 2020)

This study aims to evaluate the efficiency of 39 airports in Türkiye (shown in yellow in Figure 2) between 2015 and 2019 using the Network DEA model. Out of the 56 total airports in Türkiye, 17 airports were not included in the study as their data were not available. The introduction is followed by a literature review focusing on the use of DEA and other techniques in the evaluation of airport efficiency. Then, the research methodology is presented, including the sample of airports that will be Finally, the results of the analyses are presented.

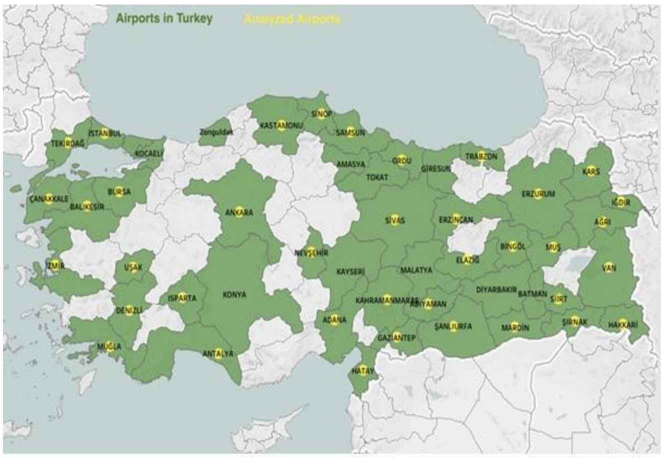

Figure 2. Active Turkish Commercial Airports in 2021 (own illustration)

2. Literature Review

Looking at overall economic and financial performance, industry figures generally show that the airport industry is achieving relatively high profit margins. One of the main questions with airport costs is whether economies of scale exist and whether unit costs decrease as output increases (Graham, 2018). From a cost perspective, a significant reason for the long-term concept of economies of scale is that airports tend to have a relatively high share of the fixed costs associated with the provision of infrastructure (runway and terminal) and certain services (security, safety) to be performed relatively independently of the traffic levels. Similarly, it can be assumed that economies of scale may well exist due to a few disadvantageous factors for larger airports, such as the need to coordinate or replicate services and facilities efficiently. Especially in the case of multiple terminals, the shortage of cheap sources (land and labor), higher costs associated with reducing environmental impacts, and difficulties with ensuring adequate surface access to and from the airport pose significant challenges (Kamp et al., 2007). Furthermore, profit alone cannot be a robust and comprehensive indicator of true economic performance. Therefore, one of the most popular airport economic empirical research areas is related to productivity and economic performance. Consequently, in the last two decades there has been considerable interest in the use of economic techniques to produce a single multidimensional measure of performance or efficiency. In general, three main methods have been used: total factor productivity (TFP), which is an average index number approach; the most popular is the data envelopment analysis (DEA) method, which relates a weighted input index to a weighted output index using a linear programming technique (Graham, 2018).

In this perspective, applied studies were represented with these methods Barros (2008); Bazargan and Vasigh (2003); Fung et al. (2008); Gillen and Lall (1997); Hooper and Hensher (1997); Lin and Hong (2006); Pathomsiri et al. (2008); Pels et al. (2001); Sarkis (2000); Yoshida (2004). In addition to these studies, in the last decade, some selected studies are represented in Table-2. This selection was made to show different regions' studies with contemporary methods. While the earliest studies used the classic DEA approach to analyze airports, current studies focus on new techniques with DEA (Lee & Kim, 2018; lo Storto, 2018; Merkert & Mangia, 2014; Olfat et al. 2016; Pacagnella Junior et al., 2020). In this context, this study presents a new technique for Türkiye's airport efficiency measurement firstly. Consequently, existing research has classified the service process or stage as having serial, parallel, or interrelated stages. The common feature of all these approaches is that each process stage has its own inputs and outputs and operates at a more acceptable level, allowing for intermediate flows between processes (Lozano et al., 2009). In other words, this approach can reveal the efficiency losses between processes more clearly. Moreover, this study shows inefficiencies that the management team at airports in Türkiye should be aware of and pay more attention to. It also enables the inclusion of external factors in the modeling. Another contribution of this study is the first-time application of population as an exogenous factor for Turkish airports.

Application of new DEA models and the operational variables, environmental variables, or factors (such as population, GDP, GDP per Capita) can affect the efficiency score of airports (Lozano et al., 2009; Merkert & Mangia, 2014). However, a few studies considered these environmental factors to the airports' efficiencies (Chi-Lok & Zhang, 2009; Ha et al., 2013; Tsui et al., 2014; Yu, 2010). Considering the region examined by this study, it is seen that two-stage network data envelopment analysis was not performed by taking environmental factors into account. In addition to this, the study shows the differences in efficiency scores as an efficiency gap between private and publicly operated airports in Türkiye.

3. Materials and Methods

3.1. Data

The dataset was collected from DHMI's annual reports between 2015 and 2019 (DHMI, 2015, 2016, 2017, 2018, 2019). The available airports (yellow) are shown in Figure 2. In addition, 17 airports were not included in the sample because the required quantitative data was not available. Table 1 shows the data categorization and fully explains the variables, with referenced studies explaining why these variables were selected.

Table 1. Efficiency Data Classification

Input/Output	Variables	Explanation	Resources
4	Runway (m^2)	The total area of ground on which aircraft take off and land in the airport	Olfat et al. (2016)
	Apron (m^2)	The total area of tarmac in an airport, outside a hangar for parking aircraft	Lozano et al. (2009)
	Terminal (m^2)	The total area of departure and arrival building at an airport	Lozano et al. (2013)
	Employees	Number of people employed in an airport	Merkert and Mangia (2014)
Intermediate Outputs	Terminal Capacity	The total capacity of departure and arrival building at an airport	Yu (2010)
	Runway Capacity	The total capacity of aircraft take off and land in the airport	
Environmental (Exogenous) Factor	Population	The people living in cities	Ha et al. (2013)
Outputs	Air Traffic	Total number of aircraft's takeoff and landing from the airport	Wanke and Barros (2017)
	Passenger Traffic	Total number of passengers who arrive and depart from the airport	Pathomsiri et al. (2008)

Turkish airports are managed both privately and publicly. For this reason, the number of employees can vary considerably. Since there is no access to the number of staff at public and privately operated airports, an assumption has been made on the number of staff. With this assumption; the number of employees is based on DHMI employee numbers for each airport. With this assumption, it is considered that the personnel structure can be considered homogenous at each airport.

3.2. Network Data Envelopment Analysis

DEA has been extensively performed to evaluate the relative effectiveness of decision-making units (DMUs). This is applied to the same inputs to produce the same outputs since Charnes et al. (1978). It is indicated that each DMU performs efficiently. It is calculated for converting inputs to outputs compared to other DMUs. While reducing inputs or increasing output will improve their performance, an issue of more significant concern to inefficient DMUs is what factors cause inefficiency (Kao & Hwang, 2010). To solve this problem, much effort has been devoted to breaking down overall efficiency into components to identify sources of inefficiency (Banker et al., 1984). With the studies of Färe & Grosskopf (1996) and Seiford & Zhu (1999), the production process was divided into sub-processes. A model of two studies Kao (2014) and Kao & Hwang (2010) is applied to measure Turkish airports within this framework. This network DEA model is input-oriented and constant to return scale (CRS). Therefore, the results will be the same when the constant return scale (CRS) and the variable return scale (VRS) are applied to the model. This model generalizes the relational two-stage structure that allows both stages to consume an exogenously supplied input and produce final outputs, as shown in Figure 3.

Network DEA Model:

$$E_k = max \sum_{r=1}^{s} U_r \times Y_{r0}$$

$$i: inputs\ (i = 1, \dots, m)$$
$$r: outputs\ (r = 1, \dots, s)$$
$$l: intermediate\ outputs\ (l = 1, \dots, t)$$
$$p: process\ (p = 1, \dots, q)$$
$$j: DMU\ (j = 1, \dots, n)$$

Subjects to:

$$\sum_{i=1}^{m} U_i \times X_{i0} = 1$$

$$\sum_{r=1}^{s} U_r \times Y_{rj} - \sum_{i=1}^{m} U_i \times X_{ij} \le 0, \qquad j = 1, \dots, n$$

$$\left\{\sum_{r\in 0^p} U_r \times Y_{rj}^p + \sum_{l\in M^P} w_l \times Z_{lj}^p\right\} - \left\{\sum_{i\in I^p} U_i \times X_{ip}^p + \sum_{l\in M^{(P-1)}} w_l \times Z_{lj}^{(p-1)}\right\} \le 0,$$

$$j = 1,\ldots,n\ , p = 1,\ldots,q$$

$$U_r, U_i, W_l \geq \varepsilon$$
$$r = 1,\ldots,s;\ i = 1,\ldots,m;\ l = 1,\ldots,t$$

$$E_0^p = \left(\sum_{r\in 0^p} U_r^* \times Y_{rj}^p + \sum_{l\in M^P} W_l^* \times Z_{lj}^p\right) \div \left(\sum_{i\in I^p} U_i^* \times X_{ip}^p + \sum_{l\in M^{(P-1)}} w_l \times Z_{lj}^{(p-1)}\right)$$

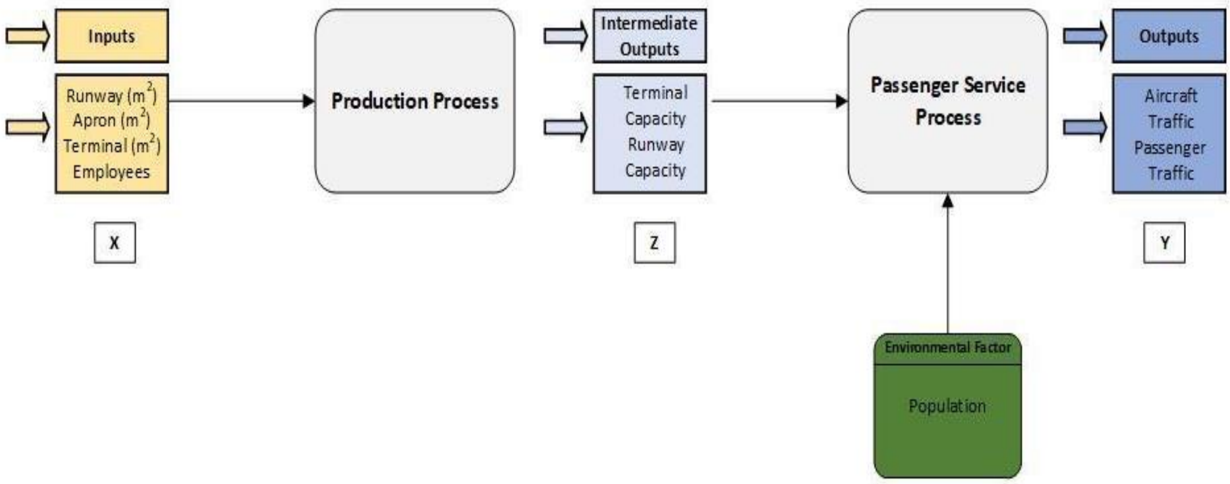

Figure 3. Network DEA Flow Chart with Environmental (Exogenous) Factor (own illustration)

4. Findings

The Network DEA model was solved via version 28.4 of The General Algebraic Modeling System (GAMS) software system, a high-level modeling system for mathematical optimization. The results obtained are as follows:

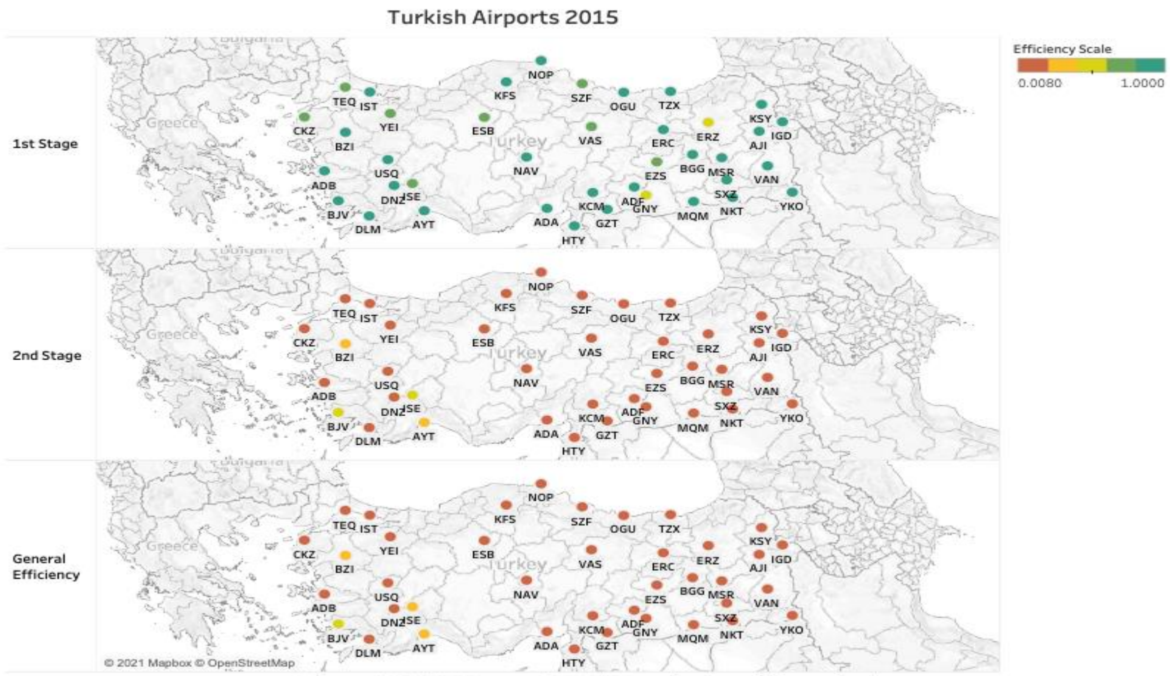

Figure 4. 2015 Network DEA Results (own illustration)

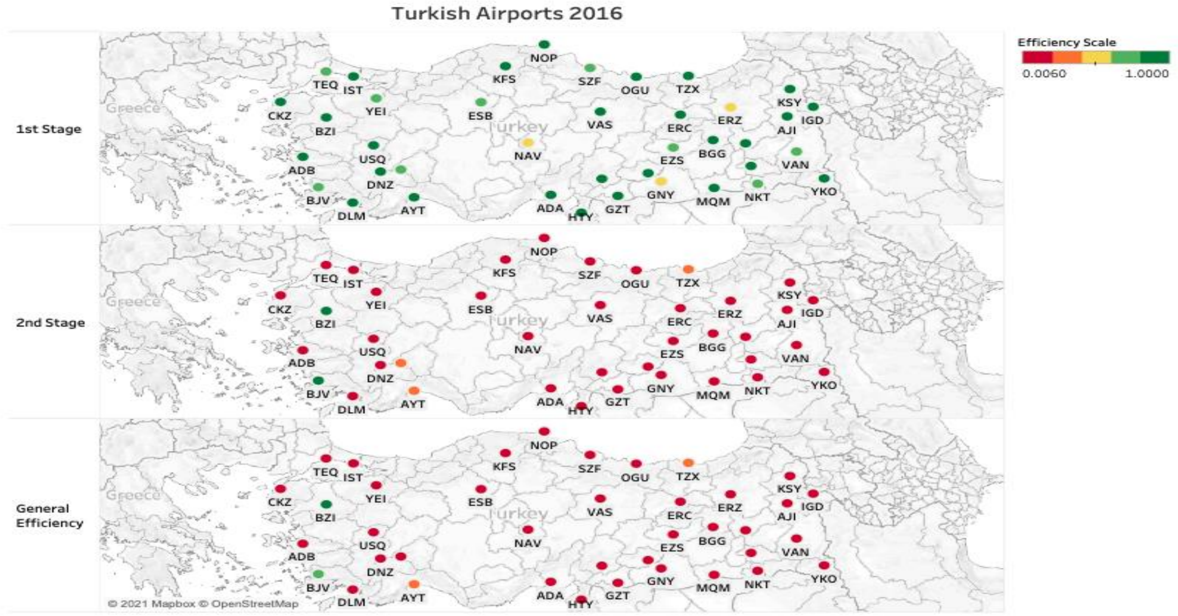

Figure 5. 2016 Network DEA Results (own illustration)

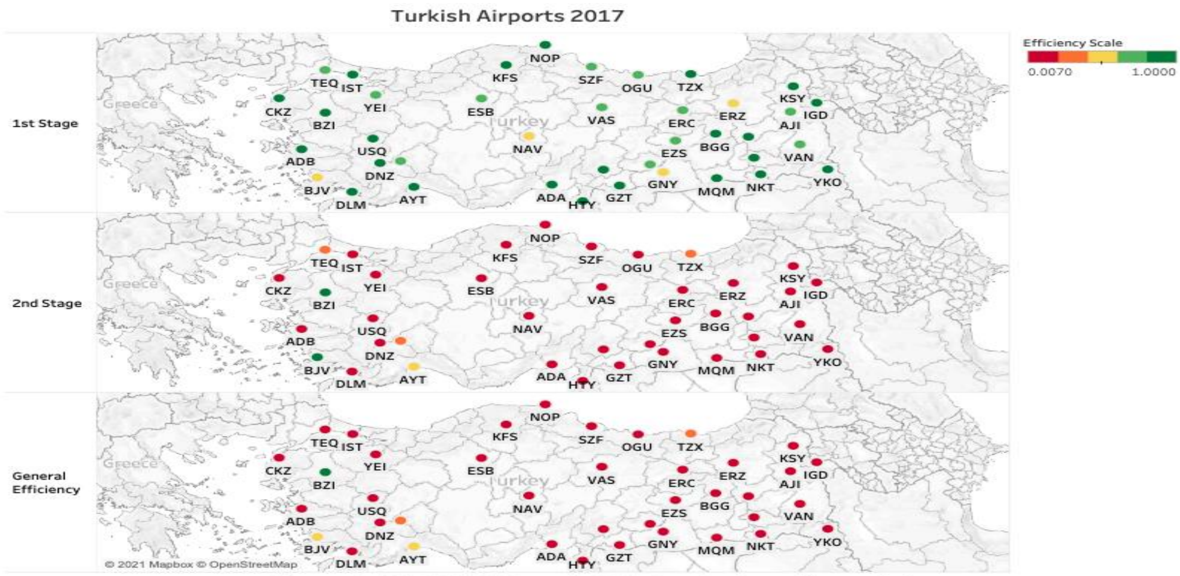

Figure 6. 2017 Network DEA Results (own illustration)

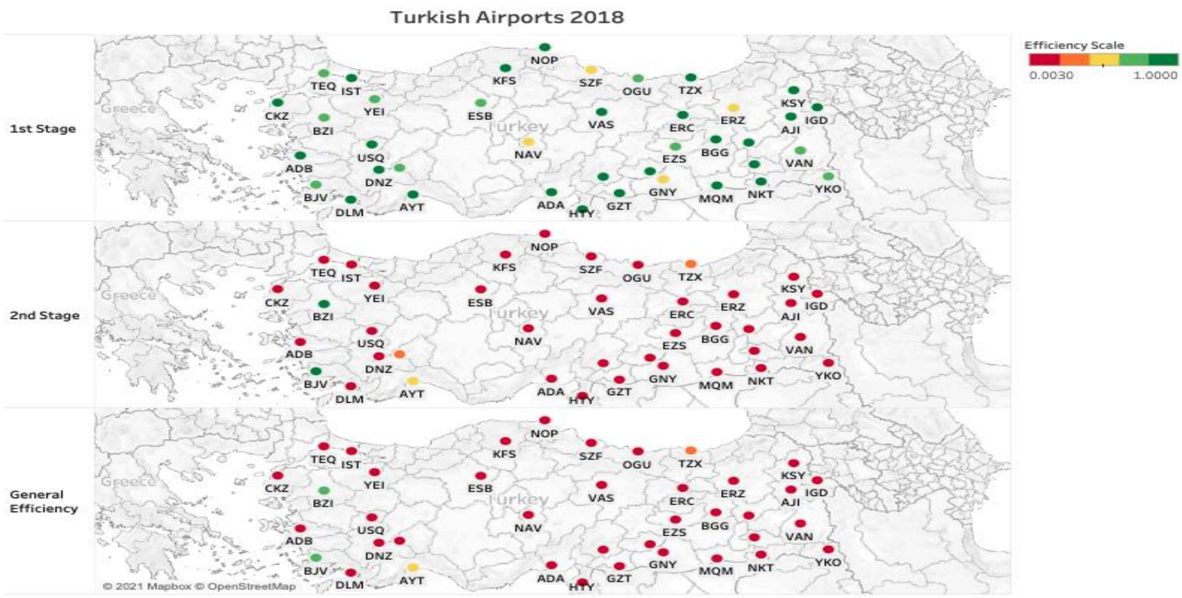

Figure 7. 2018 Network DEA Results (own illustration)

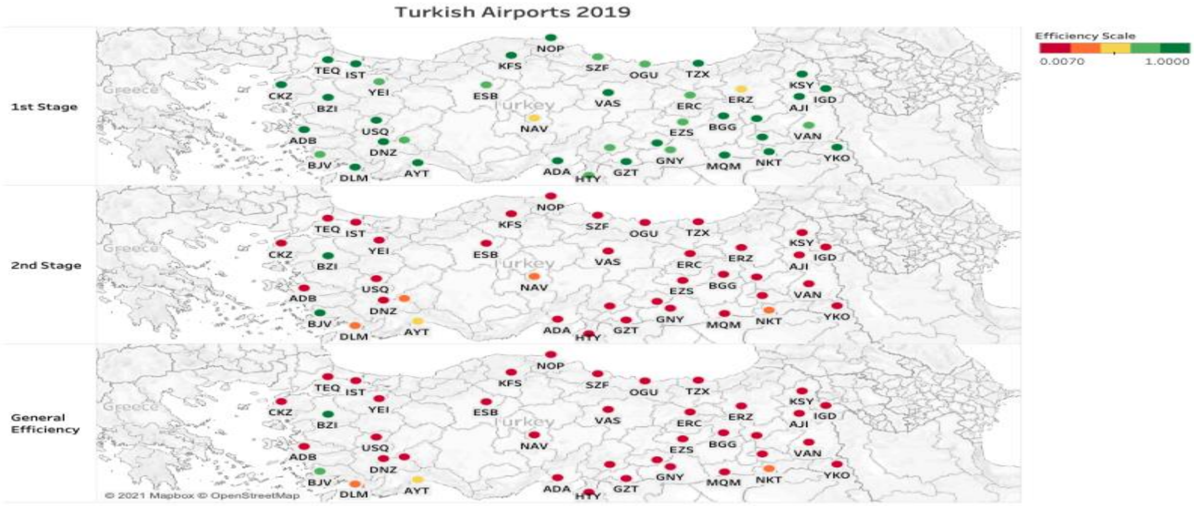

Figure 8. 2019 Network DEA Results (own illustration)

The model results are colored using an efficiency scale and shown on a map of Türkiye with airports from Figure 4 to Figure 8. In addition, the full results of the model are given in the appendix. Airports in densely populated areas are more efficient than those in less densely populated areas, according to Örkcü et al. (2016). However, this study shows that less populated airports such as BZI (Balıkesir Koca Seyit) and BJV (Milas-Bodrum) may be more efficient than others. Moreover, these airports are efficient in all phases of the different study periods. Tourism seems to have a significant impact on this result. Because both domestic and international airports are preferred for leisure travel. However, other airports with the same characteristics, such as AYT (Antalya) and DLM (Dalaman) are not efficient in this period. Moreover, it has been observed that airports also have an impact on the efficiency of the managers who manage them. Therefore, in this study, a two-dimensional plot graph is used to reveal the relationship between efficiency and management type (public or private). The plot is shown in Figure 9. The percentage of efficiency disclosed for each airport can be used to interpret both dimensions. The further an airport of a given size is from zero, the more critical that stage is for efficiency. In other words, it is desirable that the coordination efficiency score is closest to the perfect coordinate (1,1). A cursory glance at Figure 9 reveals that private entrepreneurs (except ESB-Ankara) are more efficient than airports controlled by public authorities.

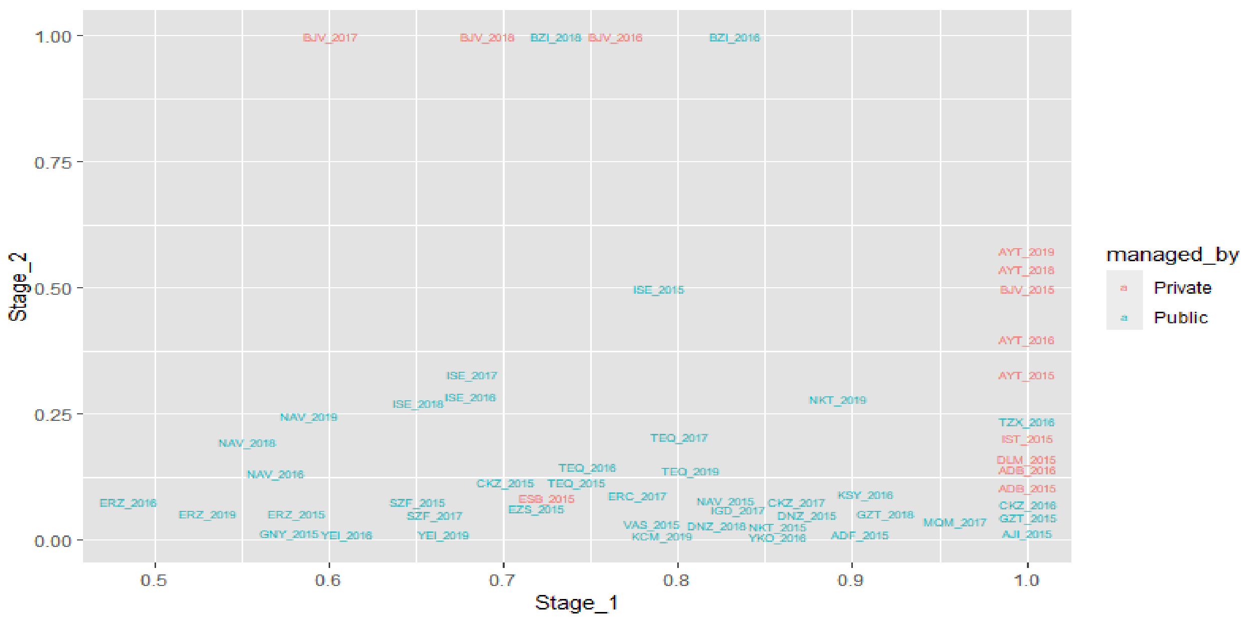

Figure 9. Efficiency Distribution of Airports by Management Type

5. Conclusion

Classical DEA models, which ignore its internal structure and treat the system as a black box, are usually used to determine the efficiency of a system. However, efficiency calculations aim to identify areas of weakness so that reasonable efforts can be made to improve performance. Therefore, when a production system can be divided into two sub-processes, more satisfactory results can be obtained in the analysis. In summary, more informative results can be obtained if the interactions of the processes within the system are taken into account. In order to avoid the possibility of multiple solutions that would distort the comparison, the efficiency of the first sub-process is maximized in a second stage under the constraint of keeping the overall efficiency score at the same level. In this model, the overall efficiency is the product of the efficiencies of the two subprocesses. This mathematical relationship between overall efficiency and component efficiencies appropriately captures the expectations of the overall process and the relationship between the two subprocesses.

For this purpose, 39 Turkish airports are analyzed in two stages of network DEA in this study. This is the first study to measure Turkish airports together with environmental factors in a two-stage network DEA. The population variable is an environmental factor that is analyzed to see how it affects airport efficiency. The results showed that this factor positively affects the efficiency score of airports with tourist attractions. According to this result, it is considered that future research would be useful to evaluate the extent to which environmental factors affect the efficiency of airports. In addition, the plot graph provides convincing evidence of the link between efficiency and management type at airports in Türkiye. When airports managed by the public and private sectors are compared, the private sector is more efficient. In conclusion, this study represents a new approach to determining the efficiency of airports in Türkiye. Globally, the environmental impacts of aviation are both evaluated and studies are being carried out by international and national authorities to take precautions. In future studies, the network model in this study or a new stage network model approach and other environmental factors can be taken into account to evaluate the issue in different dimensions. Environmental considerations should be investigated both globally and locally.

Ethical approval

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Both authors have contributed equally to the paper. Both authors read and approved the final manuscript.

References

Abbott, M. (2015). Reform and efficiency of New Zealand's airports. Utilities Policy, 36, 1-9.

Asker, V. (2016). The measurement of airports operational effectiveness: an application of the major 10 airports in Turkey. Transport & Logistics, 16(41).

Asker, V., & Battal, Ü. (2017). Operational efficiency measurement at selected airports. Uluslararası Yönetim İktisat ve İşletme Dergisi, 13(13), 351-368.

Asker, V., & Yaşar, M. (2018). Measurement of efficiency with Data Envelopment Analysis and Malmquist Total Factor Productivity methods: An application on major airports in Turkey. Transport & Logistics: the International Journal, 45, 18.

ATAG. (2020). A Global Industry, Driving Sustainable Development. https://aviationbenefits.org/media/167517/aw-oct-final-atag_abbb-2020-publication-digital.pdf

Baltazar, M. E., Jardim, J., Alves, P., & Silva, J. (2014). Air transport performance and efficiency: MCDA vs. DEA approaches. Procedia-Social and Behavioral Sciences, 111, 790-799.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science, 30(9), 1078-1092.

Barros, C. P., & Dieke, P. U. (2007). Performance evaluation of Italian airports: A data envelopment analysis. Journal of Air Transport Management, 13(4), 184-191.

Barros, C. P. (2008). Airports in Argentina: Technical efficiency in the context of an economic crisis. Journal of Air Transport Management, 14(6), 315-319.

Bazargan, M., & Vasigh, B. (2003). Size versus efficiency: a case study of US commercial airports. Journal of Air Transport Management, 9(3), 187-193.

Bloomberg. (2021). Retrieved 27.12.2021 from https://www.bloomberght.com/karaismailoglu-havalimani- sayisi-gelecek-yil-56-dan-61-e-cikacak-2295298

Chang, Y.-T., Park, H. K., Zou, B., & Kafle, N. (2016). Passenger facility charge vs. airport improvement program funds: A dynamic network DEA analysis for US airport financing. Transportation Research Part E: Logistics and Transportation Review, 88, 76-93.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. European journal of operational research, 2(6), 429-444.

Chi-Lok, A. Y., & Zhang, A. (2009). Effects of competition and policy changes on Chinese airport productivity: An empirical investigation. Journal of Air Transport Management, 15(4), 166-174.

DHMI. (2015). DHMI Annual Report 2015. https://www.dhmi.gov.tr/Lists/AnnualReports/Attachments/9/Annual_Report_2015_site.pdf

DHMI. (2016). DHMI Annual Report 2016. https://www.dhmi.gov.tr/Lists/AnnualReports/Attachments/10/Annual_Report_2016.pdf

DHMI. (2017). DHMI Annaul Report 2017. https://www.dhmi.gov.tr/Lists/AnnualReports/Attachments/11/Annual_Report_2017.pdf

DHMI. (2018). DHMI Annual Report 2018. https://www.dhmi.gov.tr/Lists/AnnualReports/Attachments/12/DHMI_2018_Annual_Report.pdf

DHMI. (2019). DHMI Annual Report 2019. https://www.dhmi.gov.tr/Lists/AnnualReports/Attachments/13/2019.pdf

DHMI. (2020). https://www.dhmi.gov.tr/Sayfalar/EN/Statistics.aspx

Färe, R., & Grosskopf, S. (1996). Productivity and intermediate products: A frontier approach. Economics Letters, 50(1), 65-70.

Fragoudaki, A., Giokas, D., & Glyptou, K. (2016). Efficiency and productivity changes in Greek airports during the crisis years 2010–2014. Journal of Air Transport Management, 57, 306-315.

Fung, M. K. Y., Wan, K. K. H., Van Hui, Y., & Law, J. S. (2008). Productivity changes in Chinese airports 1995–2004. Transportation Research Part E: Logistics and Transportation Review, 44(3), 521-542.

Gillen, D., & Lall, A. (1997). Developing airport productivity and performance measures: an application of data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review, 33(4), 261-273.

Graham, A. (2018). Airport economics and finance. In The Routledge Companion to Air Transport Management (pp. 189-205). Routledge.

Gutiérrez, E., & Lozano, S. (2016). Efficiency assessment and output maximization possibilities of European small and medium-sized airports. Research in Transportation Economics, 56, 3-14.

Güner, S., Cebeci, H. İ., Antunes, J. J. M., & Wanke, P. F. (2021). Sustainable efficiency drivers in Eurasian airports: Fuzzy NDEA approach based on Shannon's entropy. Journal of Air Transport Management, 92, 102039.

Ha, H.-K., Wan, Y., Yoshida, Y., & Zhang, A. (2013). Airline market structure and airport efficiency: Evidence from major Northeast Asian airports. Journal of Air Transport Management, 33, 32-42.

Hong, S.-J., & Jeon, M. (2019). The technical efficiency of French regional airports and low-cost carrier terminals. Sustainability, 11(18), 5107.

Hooper, P. G., & Hensher, D. A. (1997). Measuring total factor productivity of airports—an index number approach. Transportation Research Part E: Logistics and Transportation Review, 33(4), 249-259.

Kamp, V., Niemeier, H.-M., & Müller, J. (2007). What can be learned from benchmarking studies? Examining the apparent poor performance of German airports. Journal of Airport Management, 1(3), 294-308.

Kao, C. (2014). Network data envelopment analysis: A review. European journal of operational research, 239(1), 1-16.

Kao, C., & Hwang, S.-N. (2008). Efficiency decomposition in two-stage data envelopment analysis: An application to non-life insurance companies in Taiwan. European journal of operational research, 185(1), 418-429.

Kao, C., & Hwang, S.-N. (2010). Efficiency measurement for network systems: IT impact on firm performance. Decision Support Systems, 48(3), 437-446.

Keskin, B., & Köksal, C. D. (2019). A hybrid AHP/DEA-AR model for measuring and comparing the efficiency of airports. International Journal of Productivity and Performance Management.

Koçak, H. (2011). Efficiency examination of Turkish airports with DEA approach. International Business Research, 4(2), 204.

Lee, M. J., & Kim, C. (2018). A network DEA aeronautical and non-aeronautical production model: an application to South Korea airports. Journal of Economic Structures, 7(1), 1-12.

Lin, L., & Hong, C. (2006). Operational performance evaluation of major international airports: An application of data envelopment analysis. Journal of Air Transport Management, 12(6), 342-351.

Lo Storto, C. (2018). The analysis of the cost-revenue production cycle efficiency of the Italian airports: A NSBM DEA approach. Journal of Air Transport Management, 72, 77-85.

Lozano, S., Gutiérrez, E., & Moreno, P. (2013). Network DEA approach to airports performance assessment considering undesirable outputs. Applied Mathematical Modelling, 37(4), 1665-1676.

Lozano, S., Gutiérrez, E., & Salmerón, J. L. (2009). Network DEA models in transportation. Application to airports. German Aviation Research Society Seminar on Airport Benchmarking,

Lu, W., Park, S. H., Huang, T., & Yeo, G. T. (2019). An analysis for Chinese airport efficiency using weighted variables and adopting CFPR. The Asian Journal of Shipping and Logistics, 35(4), 230-242.

Merkert, R., & Mangia, L. (2014). The efficiency of Italian and Norwegian airports: A matter of management or the level of competition in remote regions? Transportation Research Part A: Policy and Practice, 62, 30-38.

Ngo, T., & Tsui, K. W. H. (2020). A data-driven approach for estimating airport efficiency under endogeneity: An application to New Zealand airports. Research in Transportation Business & Management, 34, 100412.

Olfat, L., Amiri, M., Soufi, J. B., & Pishdar, M. (2016). A dynamic network efficiency measurement of airports performance considering sustainable development concept: A fuzzy dynamic network-DEA approach. Journal of Air Transport Management, 57, 272-290.

Örkcü, H. H., Balıkçı, C., Dogan, M. I., & Genç, A. (2016). An evaluation of the operational efficiency of Turkish airports using data envelopment analysis and the Malmquist productivity index: 2009–2014 case. Transport Policy, 48, 92-104.

Özsoy, V. S., & Örkcü, H. H. (2021). Structural and operational management of Turkish airports: a bootstrap data envelopment analysis of efficiency. Utilities Policy, 69, 101180.

Pacagnella Junior, A. C., Hollaender, P. S., Mazzanati, G. V., & Bortoletto, W. W. (2020). Infrastructure and Flight Consolidation Efficiency of Public and Private Brazilian International Airports: A Two-Stage DEA and Malmquist Index Approach. Journal of Advanced Transportation, 2020.

Pathomsiri, S., Haghani, A., Dresner, M., & Windle, R. J. (2008). Impact of undesirable outputs on the productivity of US airports. Transportation Research Part E: Logistics and Transportation Review, 44(2), 235-259.

Pels, E., Nijkamp, P., & Rietveld, P. (2001). Relative efficiency of European airports. Transport Policy, 8(3), 183-192.

Ripoll-Zarraga, A. E., & Mar-Molinero, C. (2020). Exploring the reasons for efficiency in Spanish airports. Transport Policy, 99, 186-202.

Sarkis, J. (2000). An analysis of the operational efficiency of major airports in the United States. Journal of Operations Management, 18(3), 335-351.

Seiford, L. M., & Zhu, J. (1999). Profitability and marketability of the top 55 US commercial banks. Management Science, 45(9), 1270-1288.

Song, K. H., Choi, S., & Han, I. H. (2020). Competitiveness Evaluation Methodology for Aviation Industry Sustainability Using Network DEA. Sustainability, 12(24), 10323.

Stichhauerova, E., & Pelloneova, N. (2019). An efficiency assessment of selected German airports using the DEA model. Journal of Competitiveness, 11(1), 135-151.

Tsui, W. H. K., Balli, H. O., Gilbey, A., & Gow, H. (2014). Operational efficiency of Asia–Pacific airports. Journal of Air Transport Management, 40, 16-24.

TUIK.(2020). https://data.tuik.gov.tr/Kategori/ GetKategori?p=dis-ticaret-104&dil=1

Ülkü, T. (2015). A comparative efficiency analysis of Spanish and Turkish airports. Journal of Air Transport Management, 46, 56-68.

Wanke, P., & Barros, C. (2017). Efficiency thresholds and cost structure in Senegal airports. Journal of Air Transport Management, 58, 100-112.

Yoshida, Y. (2004). Endogenous-weight TFP measurement: methodology and its application to Japanese-airport benchmarking. Transportation Research Part E: Logistics and Transportation Review, 40(2), 151-182.

Yu, M.-M. (2010). Assessment of airport performance using the SBM-NDEA model. Omega, 38(6), 440-452.

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Appandix

Table 2. Summary of Literature on Airport Efficiency Measurement

Source	Method	Sample Data	Input(s)	Output(s)
Barros and Dieke (2007)	DEA	Italian Airports	Labor costs, capital invested, and operational costs (excluding labor)	Number of planes and passengers, cargo, receipts of handling-aeronautical-commercial
Koçak (2011)	DEA	40 Turkish Airports	Operational expenses, number of personnel, annual flight traffic, number of passengers	Number of passengers/areas, total flight traffic/runway, total cargo traffic, operational revenues
Baltazar et al. (2014)	DEA&MCDA	3 Iberian Airports	Number of runways, aircraft parking stands, passenger and cargo terminal areas, number of boarding gates, check-in desks, baggage carousels	Aircraft movements, processed passengers and cargo
Merkert and Mangia (2014)	2 Stage DEA and Truncated Reg.	35 Italian and 45 Norwegian Airports	Terminal area, number of runways, runway area and length, apron area, total area, employees, operating cost, staff cost, material cost	Air traffic movements, passengers, cargo
Abbott (2015)	1st stage: Malmquist DEA 2nd stage: Benchmark	1st stage 3 Major New Zealand's Airports, 2nd stage 13 Airports	Runway length, operating expense	Aircraft and passenger movements, cargo
Ülkü (2015)	DEA	Spain and Turkish Airports	Staff costs, other operating costs, and runway area	Number of passengers and air traffic movements, cargo, and commercial revenue
Asker (2016)	DEA	10 Turkish Airports	Runway number, terminal field size, and check-in counter number	Passenger number and flight number
Chang et al. (2016)	2 Stage Dynamic Network DEA	41 US Airports	Aircraft movement, labor and materials costs, net asset, promotions	Flight delay, aircraft loading, and operations
Fragoudaki et al. (2016)	DEA-Malmquist Index	Greek Airports	Runway lengths, apron size, and passenger terminal size	Total aircraft movements and passengers, cargo
Gutiérrez and Lozano (2016)	DEA	21 Small and Medium European Airports	Runway size, boarding gates, apron stands, number of airlines, number of scheduled routes	Aircraft movements, passenger throughput, cargo handled
Olfat et al. (2016)	2 Scale Dynamic Network Fuzzy DEA	59 Iranian Airports	Policy concept, budget, social responsibility (link), number of taking off and landing aircraft (link), service quality (link), corporate reputation	Pollution levels, satisfaction, non-aviation income
Örkcü et al. (2016)	DEA-Malmquist Index	21 Turkish Airports	Number of runways, dimension of runway units, passenger terminal area	The annual number of flights, yearly passenger and cargo throughputs,
Asker and Battal (2017)	DEA	20 International Airports	Numbers of runway-airplanes-gates and size of terminal area	Total numbers of passengers and flights, total load

Stichhauerova and Pelloneova (2019)	DEA	27 German Airports	Number of employees, terminals, runways, the airport area, capacity, distance from city center	Number of passengers, aircraft movements, amount of cargo
Asker and Yaşar (2018)	DEA-Malmquist Index	19 Turkish Airports	Number of runway and gate, terminal size area, number of employee, and total expense	Total number of passengers and commercial flights, Freight, and total revenue
lo Storto (2018)	3 Stage Network-Slack Based DEA	38 Italian Airports	Soft operating expense, labor cost, terminal size, apron size, runways, employees, movements, passengers, cargo	Aviation and non-aviation revenues
Wanke and Barros (2017)	1st stage: DEA 2nd stage: Support Vector Machine Reg.	5 Senegal's Airport	Personnel, runway length, contextual variables (cost of labor-capital-operations, cargo operation, cost asset ratio)	Passengers, cargo, aircraft
Lee and Kim (2018)	Network DEA	14 South Korean Airports	1st stage: Total capacity, duty-free store size, restaurant size, parking lot capacity, total workers, runway, terminal capacity 2nd stage: Aircraft movement	Aeronautical and non-aeronautical revenues, cargo, passengers
Hong and Jeon (2019)	DEA-Malmquist Index	99 Regional French Airports	Employees, labor cost, debt, subsidization, operational cost	Passenger, cargo, movement, revenue, net profit
Keskin and Köksal (2019)	AHP/DEA-AR Model	48 Turkish Airports	Number of gates, employees, runways area, terminal area, operational expenditure	Aircraft movements, number of passengers, amount of cargo, total revenue
Lu et al. (2019)	Window DEA AR Model	27 Chinese Airports	Aircraft parking spaces, capital invested, number of air routes, boarding gate, runways, terminal area	Aircraft movements, cargo throughput, number of passengers
Ngo and Tsui (2020)	Window Slack Based Measure DEA and Tobit Model	11 New Zealand's Airports	Employee and Operating expenses, length of runways,	Aeronautical and non-aeronautical revenues, aircraft movements
Pacagnella Junior et al. (2020)	2 Stage DEA-Malmquist Index	33 Brazilian Airports	1st stage: Terminal area, number of aircraft parking spaces, number of runways 2nd stage: Number of landings take-offs	Number of passengers, cargo throughput
Ripoll-Zarraga and Mar-Molinero (2020)	DEA	49 Spanish Airports	Labor costs, operating costs, depreciation of airside assets	Passengers, air traffic movements, cargo, commercial revenues, % flights on time
Song et al. (2020)	Network DEA	56 Countries' Airports	1st stage: Number of routes and airports, population, GDP, tourist attraction, HHI Index 2nd stage: RPK, CTK, HHI Index	Amount of added value
Güner et al. (2021)	2 Stage Fuzzy Frontier Network DEA	23 Eurasian Airports	Runway lengths, terminal area, fuel, aircraft	Passengers, freight, environmental effect
Özsoy and Örkcü (2021)	2 Stage DEA and CART	43 Turkish Airports	Terminal sizes, car parking capacity, number of runways, number of equipment, employees	Air traffic movements, number of passengers, the volume of cargo

Table 3. Summary of Airport Efficiency Measurement

Years	2015			2016			2017			2018			2019		
Airports	**1. Stage**	**2. Stage**	**General Efficiency**	**1. Stage**	**2. Stage**	**General Efficiency**	**1. Stage**	**2. Stage**	**General Efficiency**	**1. Stage**	**2. Stage**	**General Efficiency**	**1. Stage**	**2. Stage**	**General Efficiency**
IST	1.000	0.204	0.204	1.000	0.203	0.203	1.000	0.200	0.200	1.000	0.187	0.187	1.000	0.046	0.046
ESB	0.725	0.085	0.062	0.728	0.121	0.088	0.729	0.136	0.099	0.728	0.125	0.091	0.754	0.099	0.075
ADB	1.000	0.105	0.105	1.000	0.142	0.142	1.000	0.140	0.140	1.000	0.128	0.128	1.000	0.115	0.115
AYT	1.000	0.328	0.328	1.000	0.400	0.400	1.000	0.513	0.513	1.000	0.538	0.538	1.000	0.575	0.575
DLM	1.000	0.162	0.162	1.000	0.167	0.167	1.000	0.186	0.186	1.000	0.194	0.194	1.000	0.225	0.225
BJV	1.000	0.500	0.500	0.764	1.000	0.764	0.601	1.000	0.601	0.691	1.000	0.691	0.694	1.000	0.694
ADA	1.000	0.089	0.089	1.000	0.126	0.126	1.000	0.119	0.119	1.000	0.104	0.104	1.000	0.091	0.091
TZX	1.000	0.150	0.150	1.000	0.237	0.237	1.000	0.247	0.247	1.000	0.205	0.205	1.000	0.189	0.189
ERZ	0.581	0.054	0.031	0.485	0.078	0.038	0.517	0.083	0.043	0.487	0.072	0.035	0.530	0.053	0.028
GZT	1.000	0.046	0.046	1.000	0.059	0.059	1.000	0.061	0.061	0.919	0.053	0.049	1.000	0.049	0.049
ADF	0.904	0.013	0.012	0.880	0.020	0.018	0.788	0.020	0.016	0.807	0.019	0.015	0.821	0.016	0.013
AJI	1.000	0.015	0.015	0.913	0.022	0.020	0.792	0.025	0.020	0.930	0.025	0.023	0.863	0.024	0.021
BZI	1.000	0.207	0.207	0.832	1.000	0.832	0.822	1.000	0.822	0.730	1.000	0.730	0.807	1.000	0.807
BGG	1.000	0.022	0.022	0.894	0.029	0.026	0.905	0.029	0.026	0.879	0.033	0.029	0.925	0.029	0.027
YEI	0.609	0.037	0.023	0.610	0.012	0.007	0.635	0.018	0.011	0.620	0.009	0.006	0.665	0.013	0.009
CKZ	0.701	0.115	0.081	1.000	0.071	0.071	0.868	0.077	0.067	0.821	0.071	0.058	0.888	0.055	0.049
DNZ	0.874	0.051	0.045	0.874	0.034	0.030	0.829	0.071	0.059	0.822	0.031	0.025	0.909	0.031	0.028
EZS	0.719	0.063	0.045	0.714	0.088	0.063	0.713	0.083	0.059	0.656	0.072	0.047	0.715	0.062	0.044
ERC	1.000	0.053	0.053	0.840	0.076	0.064	0.777	0.089	0.069	0.814	0.087	0.071	0.791	0.072	0.057
YKO	1.000	0.114	0.114	0.857	0.007	0.006	0.853	0.028	0.024	0.798	0.032	0.026	0.824	0.036	0.030
HTY	1.000	0.030	0.030	0.876	0.038	0.033	0.852	0.038	0.032	0.841	0.034	0.029	0.794	0.030	0.024
IGD	1.000	0.042	0.042	0.872	0.056	0.049	0.834	0.060	0.050	0.934	0.060	0.056	0.905	0.053	0.048
ISE	0.789	0.500	0.395	0.681	0.286	0.195	0.682	0.328	0.224	0.651	0.272	0.177	0.683	0.268	0.183
KCM	0.874	0.014	0.012	0.874	0.012	0.010	0.870	0.014	0.012	1.000	0.012	0.012	0.791	0.010	0.008
KSY	1.000	0.056	0.056	0.908	0.091	0.083	0.896	0.094	0.084	1.000	0.082	0.082	1.000	0.074	0.074
KFS	1.000	0.014	0.014	1.000	0.014	0.014	1.000	0.014	0.014	1.000	0.015	0.015	1.000	0.010	0.010
MQM	1.000	0.028	0.028	1.000	0.040	0.040	0.959	0.039	0.037	1.000	0.035	0.035	1.000	0.027	0.027
MSR	1.000	0.033	0.033	1.000	0.046	0.046	1.000	0.051	0.051	1.000	0.046	0.046	1.000	0.038	0.038
NAV	0.827	0.079	0.065	0.569	0.134	0.076	0.585	0.058	0.034	0.553	0.194	0.107	0.588	0.248	0.146
OGU	1.000	0.008	0.008	0.844	0.033	0.028	0.720	0.047	0.034	0.659	0.037	0.024	0.663	0.036	0.024
SZF	0.651	0.076	0.049	0.661	0.084	0.056	0.661	0.051	0.034	0.601	0.054	0.032	0.663	0.062	0.041
SXZ	1.000	0.038	0.038	1.000	0.028	0.028	1.000	0.007	0.007	1.000	0.003	0.003	1.000	0.007	0.007
NOP	1.000	0.040	0.040	1.000	0.022	0.022	1.000	0.042	0.042	1.000	0.058	0.058	1.000	0.047	0.047
VAS	0.785	0.033	0.026	0.843	0.045	0.038	0.781	0.043	0.034	0.817	0.037	0.030	0.810	0.034	0.028
GNY	0.577	0.015	0.009	0.569	0.020	0.011	0.589	0.020	0.012	0.545	0.017	0.009	0.654	0.014	0.009
NKT	0.857	0.029	0.025	0.780	0.029	0.023	0.840	0.032	0.027	0.824	0.033	0.027	0.891	0.280	0.249
TEQ	0.742	0.115	0.085	0.748	0.147	0.110	0.801	0.206	0.165	0.741	0.115	0.085	0.807	0.138	0.111
USQ	1.000	0.023	0.023	1.000	0.018	0.018	1.000	0.020	0.020	1.000	0.023	0.023	1.000	0.091	0.091
VAN	0.808	0.048	0.039	0.603	0.067	0.040	0.696	0.073	0.051	0.650	0.072	0.047	0.695	0.073	0.051