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Comparison of State-Owned and Build-Operate-Transfer Model Airports: A Clustering Analysis of Financial and Operational Efficiency

(Research Article)

Devlet İşletmeciliğinde ve Yap-İşlet-Devret Modeli Havalimanlarının Karşılaştırılması: Finansal ve Operasyonel Verimliliğin Kümeleme Analizi

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Tüzün Tolga İNAN[1]
[1] Dr. Öğr. Üyesi, Bahçeşehir Üniversitesi, tuzuntolga.inan@bau.edu.tr, Orcid No: 0000-0002-5937-9217

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ABSTRACT

The efficiency and management structure of airports play a crucial role in the global aviation industry, impacting financial sustainability, operational performance, and overall service quality. This study examines the differences between State-Owned and Build-Operate-Transfer (BOT) model airports, using a clustering analysis approach to categorize airports based on financial and operational parameters. Türkiye, a key player in global aviation, is selected as the case study related to analyzing 49 airports (43 state-owned and 6 BOT-operated) from 2018 to 2024. Using K-Means Clustering, airports are classified into four distinct categories based on passenger traffic, aircraft movements, navigational revenues, terminal service revenues, and business service revenue paameters. The findings indicate that BOT model airports demonstrate higher financial efficiency and operational sustainability compared to their state-owned counterparts. From a managerial perspective, the study highlights the need for adaptive financial models, efficient privatization strategies, and data-driven decision-making to enhance the economic sustainability of state-owned airports.

***Anahtar Kelimeler**:*
Havalimanı Yönetimi, Yap-İşlet-Devret Modeli, Kümeleme Analizi, Finansal ve Operasyonel Verimlilik, Devlet İşletmeciliğinde Havalimanları

ÖZET

Havalimanlarının verimliliği ve yönetim yapısı, finansal sürdürülebilirliği, operasyonel performansı ve genel hizmet kalitesini etkileyerek küresel havacılık sektöründe çok önemli bir rol oynamaktadır. Bu çalışma havalimanlarını finansal ve operasyonel parametrelere göre sınıflandırmak için bir kümeleme analizi yaklaşımı kullanarak Devlete ait ve Yap-İşlet-Devret (YİD) modeli havalimanları arasındaki farkları incelemektedir. Küresel havacılıkta önemli bir oyuncu olan Türkiye vaka çalışması olarak seçilmiş ve 2018-2024 yılları arasında 49 havalimanı (43 devlete ait ve 6 YİD işletmeli) analiz edilmiştir. K-Ortalamalar Kümelemesi kullanılarak havalimanları, yolcu trafiği, uçak hareketleri, seyrüsefer gelirleri, terminal hizmet gelirleri ve ticari hizmet geliri parametrelerine göre dört farklı kategoride sınıflandırılmıştır. Bulgular YİD modeli havalimanlarının devlete ait benzerlerine kıyasla daha yüksek finansal verimlilik ve operasyonel sürdürülebilirlik sergilediğini göstermektedir. Yönetimsel bir perspektiften bakıldığında çalışma devlete ait havalimanlarının ekonomik sürdürülebilirliğini artırmak için uyarlanabilir finansal modellere, etkin özelleştirme stratejilerine ve veriye dayalı karar alma süreçlerine duyulan ihtiyacı vurgulamaktadır.

1. INTRODUCTION

In the history of civil aviation, one of the most transformative milestones was the deregulation of domestic air travel in the United States in 1978. This deregulation movement extended globally throughout the 1980s, incorporating international passenger transport and significantly accelerating the evolution of the civil aviation sector. As a result, the industry has experienced substantial changes marked by airline mergers, alliances, bankruptcies, and the emergence of new carriers factors that collectively complicate the assessment of market competition (Lijesen et al., 2002). Airports play a vital role in this dynamic and competitive environment. To illustrate this development, Türkiye's airport sector is examined as a case study, given its notable growth in recent years driven by increased competition and strategic infrastructure investment. Despite this momentum, limited research has simultaneously evaluated both the operational and financial efficiency of airports within the country. Nevertheless, airports are critical to national economic development, functioning as hubs that facilitate trade, tourism, and connectivity. The primary objective of airport management is to provide air navigation and operational services that comply with international standards, while ensuring high levels of safety, environmental responsibility, and technological advancement. Effective performance evaluation and the formulation of improvement strategies for underperforming airports are essential to support national economic growth.

In brief, Türkiye has 56 (including Atatürk Airport) airports, and 55 of them have operated (excluding Çukurova Airport due to not enough data). The management of airports in Türkiye with Turkish airspace arrangement and supervision has been operated by State Airports Management General Directorate (Devlet Hava Meydanları İşletmesi, 2019). DHMİ operates as a state-owned enterprise with legal status and operational autonomy. It functions under the jurisdiction of the Ministry of Transport and Infrastructure and is responsible for providing essential civil aviation services. This governance model is consistent with the institutional frameworks found in other developed nations, although the agencies may operate under different names. The scope of DHMİ's responsibilities includes airport management, ground handling, air traffic control, and the maintenance and development of air navigation systems and infrastructure (Örkcü et al., 2016).

Over the past decade, Türkiye's aviation sector has achieved remarkable growth. From 2010 to 2020, commercial flights increased by over 230%, passenger numbers by more than 270%, and total freight volume (including baggage, cargo, and mail) by over 250%. Prior to the COVID-19 pandemic, the total number of air passengers exceeded 230 million annually as of 2024. In addition, commercial air traffic encompassing all take-offs and landings surpassed 2.29 million movements, while total freight volume exceeded 4 million tonnes (Türkiye İstatistik Kurumu, 2025). Türkiye has expanded its international air connectivity by including Middle Eastern destinations, offering 423 routes to the region. This expansion has positioned Türkiye as a key player in the European air transport network, recording one of the highest daily additions of flight destinations in European Continent. Consequently, Türkiye ranked third in Europe and eighth globally in total air passenger volume by 2024 (International Civil Aviation Organization, 2025).

Furthermore, over the past 17 years, Türkiye has consistently ranked first in Europe in terms of transit and transfer flight volumes. İstanbul Airport (including Atatürk Airport's traffic until its closure in April 2019) became the busiest airport in Europe by passenger numbers at the end of 2022, 2023, and 2024 (Devlet Hava Meydanları İşletmesi, 2025). Türkiye has also emerged as the leading contributor to the European air traffic network during this period (Devlet Hava Meydanları İşletmesi, 2025). This study explores the structure, ownership models, and operational dynamics of Türkiye's airports, with a specific focus on comparing state-owned airports and those managed under the Build-Operate-Transfer (BOT) model. The methodology involves applying clustering analysis to assess the financial and operational efficiency of these airports. The aim is to evaluate the performance of all airports operated by DHMİ, investigating how ownership structure state-owned versus BOT model affects their overall efficiency. The clustering analysis covers the period from 2018 to 2024, providing a comprehensive evaluation of performance trends across the national airport network (Türkiye İstatistik Kurumu, 2025).

2. LITERATURE REVIEW

According to the similar studies in clustering analysis with the performance evaluation of airports, six studies were found. Only one study was analyzed the airports in Türkiye. This study was published by Yalcin and Ayyildiz (2018), used clustering techniques to investigate 55 airports that operate in Turkey. The K-means approach groups the airports based on shared characteristics. Basic characteristics including the number of flights, the cargo that airports carry, and the passengers that utilize them were employed throughout the clustering process. The airports are grouped into six clusters. The five main airports İstanbul Ataturk, İstanbul Sabiha Gokcen, Ankara Esenboga, Izmir Adnan Menderes, and Antalya are also found to be very distinct from one another. Secondly, Gao (2021) provided a novel approach to grouping commercial airports using a dataset that is rarely used. The clustering results show how an airport's destination type, geographic location, and hub status within an airline's operational network impact outward passenger flow via terminals. Thirdly, Chen and Schonfeld (2024) determined that no matter how the available parking areas which do not necessarily have to be adjacent are positioned in relation to an airport terminal or how the distribution of parking durations turns out to be, this study offered a way to quantify and optimize the access distances based on a clustering approach. The fundamental idea behind this study is that it can lower average access distances and associated access times by assigning the more accessible and close-by parking spots to users who have shorter dwell times (allowing many users to use those spaces frequently) and the more distant spots to long-term users.

Fourthly, Lin et al., (2023) were categorized the airport terminal buildings by using clustering analysis according to their unique cooling load characteristics. The effect of major parameters on these cooling loads was revealed and compared using Bayesian calibration and uncertainty analysis. The novel method this study offered for comprehending and controlling cooling loads demonstrated its distinctive value and helped to create and run terminals that use less energy. Fifthly, in order to address these issues, Ahmed et al., (2020) offers a systematic and concise summary of the research done on the k-means algorithm. The efficiency of various k-means algorithm variations, including their more recent advancements, is examined through experimental study of a range of datasets. Our work differs from other previous survey publications due to the comprehensive comparison of several k-means clustering techniques and the complete experimental analysis. It also provides a comprehensive and lucid overview of the k-means method and its various research avenues. Lastly, reducing flights and easing congestion at major airports are the objectives of Bao and Huan (2017)'s study. They suggested an approach to multiairport networks that optimizes flight duration and frequency. To reduce the loss of passenger travel time, a model for optimizing flight time and frequency is developed for multiairport system operation. To solve the model and compute indexes such flight time and frequency, passenger trip-time loss, and airplane model and quantity distribution, a k-means clustering approach is used.

Airport-related challenges encompass a wide range of areas, including efficiency analysis, flight scheduling, airport size and capacity, and the segmentation of passenger types. Key elements that contribute to a positive passenger experience include the availability of amenities such as cafés, ease of access to essential processes like check-in, passport and visa control, and efficient boarding and handling procedures (Adler & Golany, 2001). When selecting a hub airport (the central airport of a country mostly used by national flag carrier [airline]) must carefully evaluate factors such as passenger demand, network structure, operational efficiency, and utilization rates. These variables have a direct impact on the airline's financial performance. Additional considerations include access to technological infrastructure, runway capacity, and labor costs are crucial for ensuring reliable air traffic control ststem and overall operational safety (Adler & Berechman, 2001).

The advancement of the civil aviation sector and the rise of global competition require sound, forward-looking policy frameworks that ensure national aviation systems grow in a systematic, sustainable, and efficient manner. In developed countries, civil aviation strategic planning is typically managed at the governmental level. These strategies aim to guide stakeholders across the sector toward common national goals through coordinated and corporate efforts. However, in many developing nations, this coordinated approach is often lacking or underdeveloped (Ida & Tamura, 2005; Itani et al., 2015). In developing countries, civil aviation infrastructure and operations are usually managed by the government and are highly dependent on public financial resources. These resources are frequently insufficient to maintain, expand, or modernize the aviation sector. Consequently, a substantial portion of aviation investment is financed through international technical assistance programs, development bank loans, and increasingly, private sector capital (LEAPP, 2001). To optimize civil aviation investments in line with national interests and priorities, aviation strategy must be integrated into broader domestic transportation policy. Such integration enables coordinated development across all modes of transport—including rail, road, maritime, and port systems—and strengthens the connection between aviation and key sectors such as education, defense, international relations, trade, natural resource management, and tourism. Strategic civil aviation planning thus becomes a tool for implementing national development objectives, and transportation policy must align with broader governmental priorities. Moreover, public support is vital for the success of both aviation and associated sectors like tourism and commerce (LEAPP, 2001).

Air transportation continues to be one of the fastest-growing global industries. Despite its complex and capital-intensive nature, the industry's supply and demand have shown strong upward trends. According to the forecasts by Airbus and Boeing, global air passenger traffic is expected to grow annually by 5–6% through 2032, with the European market projected to grow by approximately 4% (Airbus, 2013; Boeing, 2013). However, the rapid growth in air traffic has led to capacity constraints, particularly at major international airports (Cohen & Paul, 2003). These constraints are exacerbated by the hub-and-spoke model used by many flag carriers, which concentrates flights into peak periods based on passenger preferences to maximize competitiveness (Fageda & Flores-Fillol, 2012). This model often leads to congestion during peak travel times, creating operational challenges at already saturated airports (Hamzawi, 1992). Currently, more than 25 major European airports operate near or at full capacity. The six busiest airports in European Continent; Heathrow, Charles de Gaulle, İstanbul (formerly Atatürk), Frankfurt, Schiphol, and Barajas handle a significant share of Europe's air traffic under increasingly constrained conditions (Madas & Zografos, 2008).

Building on the findings of Madas & Zografos (2008), several studies have examined the implications of airport capacity constraints, governance models, and performance outcomes. For instance, Graham (2014) emphasized the growing trend of airport privatization and the importance of ownership structure in shaping airport efficiency and service quality. Similarly, Oum, Yan & Yu (2008) analyzed the impact of different regulatory frameworks and ownership types on airport performance, concluding that private and corporatized airports often outperform traditional public-sector models in terms of operational efficiency. Despite these contributions, there remains a relative paucity of empirical research focused on emerging markets such as Türkiye, where a hybrid model of state-owned and BOT airports operates under a unique regulatory and economic context. This study fills that gap by providing a comparative analysis of 44 Turkish airports, classified by ownership structure, over a multi-year period. By integrating both financial and operational performance indicators and applying advanced data analytics techniques such as clustering analysis, this research offers novel insights into the effects of privatization and public-private partnerships (PPPs) on airport efficiency. Thus, the study contributes to the international literature by extending performance evaluation frameworks to the Turkish civil aviation sector by offering evidence-based guidance for future infrastructure policy and management practices.

3. OWNERSHIP STRUCTURE AND OPERATION OF AIRPORTS

3.1. State-Owned Model

In today’s civil aviation industry, operational capability plays a critical role in enabling the private sector to finance, develop, and manage airport infrastructure effectively. Until the early 1980s, airports worldwide were predominantly operated by the public sector. However, the liberalization of the airline industry—particularly in the United States led to a sharp increase in passenger volumes, driven by deregulation and expanding market access. This growth exposed inefficiencies in existing airport infrastructure and operations, especially in terms of congestion and capacity constraints. In response, airport management practices evolved to incorporate commercial principles. Airport operators began adopting systematic management frameworks that accounted for market demand, competition, and performance incentives, with the aim of improving operational standards and service quality (Gillen, 2011).

In Türkiye, the state-owned model of airport ownership and operation dates back to February 28, 1956, with the enactment of Law No. 6686, and was further reinforced by a legislative decree issued on June 8, 1984. The General Directorate of State Airports Authority (Devlet Hava Meydanları İşletmesi, DHMİ) functions as a Public Economic Institution (PEI), endowed with operational autonomy and financial accountability for its capital resources. As a legal entity operating under the Ministry of Transport and Infrastructure, DHMİ is responsible for providing air traffic control and air navigation services to all aircraft passing through Turkish airspace, in addition to managing airport operations nationwide. Historically, DHMİ has served as the principal organization overseeing airport services in Türkiye. As of 2025, 49 out of 54 civil aviation airports remain under DHMİ's direct operational control. While the state-owned model continues to be widely implemented, the operation and management of selected airports have been transferred to the private sector under fixed-term agreements. These transfers are carried out within the framework of the Build-Operate-Transfer (BOT) model, whereby private entities undertake infrastructure projects through lease-based arrangements and assume full operational responsibility for a defined concession period (Güner & Gülay, 2018).

3.2. Build-Operate-Transfer (BOT) model

The Build-Operate-Transfer (BOT) model represents a strategic approach that leverages the capabilities of the private sector in the development and management of public infrastructure. It involves the renewal, leasing, development, maintenance, and repair of existing infrastructure by private enterprises (Yalçın, 2024). This concept is detailed in the European Commission’s Green Paper, which outlines public-private partnership (PPP) models aimed at enhancing collaboration between public authorities and private entities. The BOT model specifically enables private sector participation in financing, constructing, restoring, managing, and maintaining public infrastructure projects (Commission of the European Communities, 2004). Public-private partnerships (PPPs), in essence, are contractual arrangements that align the resources and expertise of both sectors to meet public service demands particularly those requiring significant capital investment and advanced technological input (Emek, 2009).

Wall & Wall (2013) emphasize that the BOT model enhances the economic viability of public-private collaborations. By transferring part of the financial and operational responsibilities to the private sector, the BOT framework alleviates the fiscal pressure on public budgets while simultaneously improving service quality. Fundamentally, the BOT model is designed to utilize private capital and technical expertise to deliver infrastructure projects that would otherwise be challenging to fund through public means alone. In recent years, this model has gained prominence in large-scale airport investments, aligning with broader efforts to modernize civil aviation infrastructure. Airport expansion projects, particularly the construction of new terminal buildings, have increasingly adopted the BOT model approach since the early 2000s. While the BOT model significantly contributed to the growth of the aviation sector during that decade, the industry remains vulnerable to external shocks and global crises.

According to Yerlikaya (2022), the BOT system functions as a strategic financial tool, particularly in contexts where public funding is insufficient to support large-scale investments. This model reflects a broader transformation in the state's role in economic and public service provision, wherein private capital is mobilized to support the delivery of essential infrastructure. Under the BOT model's arrangement, a private investor undertakes the project and operates it for a defined concession period. Upon the conclusion of this period, the investment—along with its facilities—is transferred to the relevant public authority at no cost. The model is particularly suited to high-cost projects that demand substantial financial resources and cutting-edge technology. In this system, the private investor recoups the initial investment, along with an agreed profit margin, through the operation of the infrastructure during the concession period. In the case of airport projects, this means the private company generates returns by managing passenger and cargo services, concessions, and other revenue streams throughout the operational phase. The BOT model, therefore, offers a sustainable and performance-driven financing mechanism for the development of advanced, capital-intensive public infrastructure (TÜİK, 2025).

4. THE EXAMPLES OF STATE-OWNED AND BUİLD-OPERATE-TRANSFER MODEL (BOT) AIRPORTS IN TÜRKİYE

4.1. State-owned Airports that Benefited from Privatization

Table 1. DHMİ Airports that Transferred Their Rights by Renting Operation Process

Airport Name and City	Operation Starting Date	Total Operation Time
Çaycuma Airport – Zonguldak	04.10.2006	25 years
Gazipaşa Airport – Alanya	04.01.2008	25 years
Çıldır Airport – Aydın	26.06.2012	20 years

Source: *(DHMİ revision of Operating Budget, 2025).*

Table 2. The airports that Took the Terminal Operation Rights by DHMİ;

Airport Name and City	Airport Lease / Built Part	Operation Starting Date	Total Operation Time
Atatürk Airport – İstanbul	İstanbul International, and Domestic Lines Building, Storey Car Park, General Aviation,	16.05.2005	15 years 6 months.
Adnan Menderes Airport – İzmir	International Terminal, CIP, and Domestic Terminal	16.12.2011	20 years
Zafer Bölgesel Airport – Kütahya	Afyon, Uşak Bölgesel Airport,	24.11.2012	29 years 11 months

Source: *(DHMİ revision of Operating Budget, 2025).*

4.2. Build-Operate-Transfer Model Airports

Table 3. The Airports that Operated with the BOT Model;

Airport Name and City	Airport Lease / Built Part	Operation Starting Date	Total Operation Time
Ankara Esenboğa Airport – Ankara	New Domestic and International Lines Terminal Building	25.09.2007	15 years 8 months
İstanbul Airport – İstanbul	Operation of All Facilities	19.11.2013	25 years
Antalya Airport – Antalya	2nd Stage International Lines Terminal	23.09.2009	15 years 3 months 8 days
Bodrum Milas Airport – Muğla	International Terminal, and Domestic Lines Terminal	11.07.2014	20 years
Dalaman Airport – Muğla	Domestic, and International Terminal	22.07.2014	26 years
Adnan Menderes Airport – İzmir	1st Stage International Lines Terminal Building, CIP and Domestic Terminal	14.09.2007	17 years 3 months 17 days

Source: *(DHMİ revision of Operating Budget, 2025).*

4.3. The Examples of Solely DHMİ Operated Airports not Included in an Operation Model

Adana, Trabzon, Erzurum, Gaziantep, Adıyaman, Ağrı Ahmed-İ Hani, Amasya Merzifon, Balıkesir Koca Seyit, Balıkesir Merkez, Batman, Bingöl, Bursa Yenişehir, Çanakkale, Denizli Çardak, Diyarbakır, Elazığ, Erzincan, Çanakkale Gökçeada, Hakkâri Y. O. Selahaddin Eyyubi, Hatay, Iğdır Şehit Bülent Aydın, Isparta Süleyman Demirel, Kahramanmaraş, Nevşehir Kapadokya, Kastamonu, Kars Harakani, Kayseri, Kocaeli Cengiz Topel, Konya, Malatya, Mardin, Muş, Ordu Giresun, Samsun Çarşamba, Siirt, Sinop, Sivas Nuri Demirağ, Şanlıurfa GAP, Şırnak Şerafettin Elçi, Tekirdağ Çorlu Atatürk, Tokat, Uşak, and Van Ferit Melen Airports.

4.4. The Airports not Operated by DHMİ

İstanbul Sabiha Gökçen, Aydın Çıldır, Zafer Bölgesel, Zonguldak Çaycuma and Eskişehir Hasan Polatkan Airports are not operated by DHMİ. So, these airports are not taken place in the Clustering Analysis.

4.5. General Information About the Airports Open to Domestic and International Air Traffic Operated by DHMİ

Table 4. Turkish Airports' Opening Years

Open to Domestic-International Traffic	Opening Year	Open to Domestic Traffic	Opening year
İstanbul Atatürk Airport	1953	Adıyaman Airport	1998
Ankara Esenboğa Airport	1955	Ağrı Airport	1997
İzmir Adnan Menderes Airport	1987	Balıkesir Koca Seyit Airport	1998
Antalya Airport	1960	Diyarbakır Airport	1952
Muğla Dalaman Airport	1981	Kahramanmaraş Airport	1996
Adana Airport	1937	Mardin Airport	1941
Trabzon Airport	1957	Siirt Airport	1998
Milas Bodrum Airport	1997	Sinop Airport	1993
Süleyman Demirel Airport	1997	Tokat Airport	1995
Nevşehir Kapadokya Airport	1998	Çanakkale Gökçeada Airport	2010
Erzurum Airport	1966	Iğdır Airport	2012
Gaziantep Airport	1976	Bingöl Airport	2013
Amasya Merzifon Airport	2008	Kastamonu Airport	2013
Bursa Yenişehir Airport	2000	Şırnak Şerafettin Elçi Airport	2013
Çanakkale Airport	1995	Hakkâri Y. O. S. Eyyubi Airport	2015
Denizli Çardak Airport	1991	Balıkesir Merkez Airport	2019
Elazığ Airport	1940		
Erzincan Airport	1988		
Hatay Airport	2007		
Kars Airport	1988		
Kayseri Airport	1998		
Konya Airport	2000		
Malatya Airport	1941		
Muş Airport	1992		
Samsun Çarşamba Airport	1998		
Sivas Nuri Demirbağ Airport	1957		
Şanlıurfa Gap Airport	2007		
Tekirdağ Çorlu Airport	1998		
Uşak Airport	1998		

Van Ferit Melen Airport	1943
Antalya Gazipaşa-Alanya Airport	2010
Batman Airport	2010
Kocaeli Cengiz Topel Airport	2011
Ordu Giresun Airport	2015
İstanbul Airport	2018

Source: *(DHMİ, 2025a)*

In Table 4, the starting operation date of all domestic and international airports in Türkiye were shown.

Table 5. Turkish Airports' IATA Codes

Airport Names	IATA Code
Adana Airport	ADA
Adıyaman Airport	ADF
Ağrı Ahmed-İ Hani Airport	AJI
Amasya Merzifon Airport	MZH
Ankara Esenboğa Airport	ESB
Antalya Airport	AYT
Balıkesir Koca Seyit Airport	EDO
Batman Airport	BAL
Bingöl Airport	BGG
Bursa Yenişehir Airport	YEI
Çanakkale Airport	CKZ
Denizli Çardak Airport	DNZ
Diyarbakır Airport	DIY
Elazığ Airport	EZS
Erzincan Airport	ERC
Erzurum Airport	ERZ
Gaziantep Airport	GZT
Hakkâri Y. O. Selahaddin Eyyubi Airport	YKO
Hatay Airport	HTY
Iğdır Şehit Bülent Aydın Airport	IGD
Isparta Süleyman Demirel Airport	ISE
İstanbul Airport	IST
İzmir Adnan Menderes Airport	ADB
Kahramanmaraş Airport	KCM
Kars Harakani Airport	KSY
Kastamonu Airport	KFS
Kayseri Airport	ASR
Kocaeli Cengiz Topel Airport	KCO
Konya Airport	KYA
Malatya Airport	MLX
Mardin Airport	MQM
Muğla Dalaman Airport	DLM
Muğla Milas- Bodrum Airport	BJV
Muş Sultan Alparslan Airport	MSR
Nevşehir Kapadokya Airport	NAV
Ordu-Giresun Airport	OGU

Samsun Çarşamba Airport	SZF
Sinop Airport	NOP
Sivas Nuri Demirağ Airport	VAS
Şanlıurfa -GAP Airport	GNY
Şırnak Şerafettin Elçi Airport	NKT
Tekirdağ Çorlu Atatürk Airport	TEQ
Trabzon Airport	TZX
Van Ferit Melen Airport	VAN

Source: *(Türkiye'deki Uluslararası Havalimanları ve Kodları, 2025).*

In Table 5, the IATA codes of international airports in Türkiye are shown.

5. METHODOLOGY

This study applies a data-driven clustering approach to assess the financial and operational performance of airports in Türkiye over the period 2018-2024. The methodology involves the application of K-Means Clustering, a widely used unsupervised machine learning algorithm, to group airports into homogeneous categories based on standardized revenue and traffic indicators. This section outlines the scope of the dataset, variable selection, preprocessing procedures, clustering algorithm, and validation techniques, while also acknowledging methodological limitations and assumptions. This study is the primary one to analyze passenger traffic, aircraft movements, navigational revenues, terminal service revenues, and business service revenues together shows the difference of this study benchmarking with other studies. In addition, the contribution of the study to the academic area is using K-Means Clustering in terms of airports to classify into then under four distinct categories that were not used together before.

Türkiye currently has 57 airports, with 56 of them operational. Çukurova Airport was excluded from the analysis due to incomplete operational records. Furthermore, Atatürk and Istanbul Airport are considered together as one unit since Istanbul Airport began operations on 29 October 2018 and remained in a low-traffic transitional phase until 6 April 2019. Therefore, 55 airports were initially considered, but only 49 airports were included in the final analysis due to the availability of complete data for both financial and operational variables. The analysis includes both state-owned airports and those operating under the Build-Operate-Transfer (BOT) model. Airports not operated by DHMİ specifically Antalya Gazipaşa-Alanya, İstanbul Sabiha Gökçen, Aydın Çıldır, Zafer Bölgesel, Zonguldak Çaycuma, and Eskişehir Hasan Polatkan were excluded due to inconsistent financial reporting.

The clustering analysis is based on five variables, divided into inputs (financial) and outputs (operational):

Inputs (Financial Indicators): Navigational Service Revenue, Terminal Service Revenue, and Business Service Revenue

Outputs (Operational Indicators): Passenger Traffic, and Aircraft Movements

These data were collected from the State Airports Authority (DHMİ) and Turkish Statistical Institute (TÜİK) reports (DHMİ, 2025a; TÜİK, 2025). Financial variables reflect the revenue earned by state-owned airports, while operational variables include activity levels at both state-owned and BOT-operated airports. The selected period spans the pre-pandemic, pandemic, and post-pandemic phases, allowing for an analysis of airport performance under varying operational conditions. Similar to recommendations in Graham (2014) and Kupfer et al. (2016), including multi-year and crisis-impacted data enhances the robustness and relevance of performance clustering models in the aviation sector. Although the transitional period of Istanbul Airport (late 2018–early 2019) is acknowledged, this low-traffic period was not specifically adjusted for in the dataset, representing a methodological limitation.

To ensure valid and unbiased clustering results, several data preprocessing steps were implemented:

Cleaning: Missing or incomplete records were excluded.

Normalization: All numerical variables were standardized using Z-score normalization.

Feature Scaling: StandardScaler from the Python sklearn library was used to ensure all features contributed equally to distance calculations.

Outlier Review: Boxplots were used to visually inspect outliers. Given the small sample size, no data points were removed, although this may affect homogeneity assumptions in clustering.

The K-Means Clustering Algorithm was chosen due to its efficiency, scalability, and interpretability in handling structured numerical data. It aims to minimize the Within-Cluster Sum of Squares (WCSS), defined as:

Key assumptions of K-Means include:

- Clusters are spherical and have equal variance
- The number of clusters K is fixed in advance
- Data are numerical and normalized
- No significant outliers exist

These assumptions were partially met through preprocessing, but should be considered when interpreting the results. To determine the appropriate number of clusters, the Elbow Method was applied. This technique plots WCSS against various values of K and identifies the point where additional clusters yield diminishing returns indicating the "elbow" point. The analysis identified K = 4 as optimal, balancing interpretability and intra-cluster cohesion. Although methods such as the Silhouette Score or Gap Statistic are widely used for further cluster validation (Pham et al., 2005), these were not applied in this version of the study. Their absence is acknowledged as a limitation, and their inclusion is recommended for future research.

Despite its effectiveness, the current methodology has several limitations:

Lack of mathematical formalism: Key formulas for WCSS, standardization, and algorithm convergence were not initially provided, which limits transparency for technical readers.

Assumption constraints: K-Means assumes equal-sized clusters with homogenous variance, which may not reflect the diversity of airport profiles.

Fixed number of clusters: The manual selection of K, although justified by the Elbow Method, remains subjective.

No modeling of transition effects: The low-traffic phase of Istanbul Airport was included without adjustment, which could distort cluster centroids.

Limited validation: Additional cluster validation metrics were not employed.

The revised methodology offers a comprehensive and replicable framework for classifying Turkish airports using financial and operational indicators. The application of K-Means clustering supported by normalization and the Elbow Method provides valuable insights into airport segmentation. However, future enhancements should incorporate alternative clustering models, mathematical rigor, and validation techniques to ensure methodological robustness and generalizability.

6. FINDINGS

This section presents the results of a K-Means clustering analysis conducted on Turkish airport data from 2018 to 2024, aimed at segmenting airports based on operational and financial performance metrics. The analysis identified four distinct clusters derived from standardized values of passenger traffic, aircraft traffic, and revenue streams (navigational, terminal, and business services). Cluster analysis is a technique used in data mining and machine learning analysis that groups similar objects and places into clusters. A popular method, K-means clustering, aims to partition a set of objects into K clusters and minimize the sum of squared distances between objects and their respective cluster centers. The clustering results revealed four unique airport profiles, reflecting differing operational scales and financial structures.

Cluster 0 – Low-Traffic & Low-Revenue Airports: This group includes smaller, often regional airports with minimal activity and revenue generation. Many of these airports either serve limited destinations or are newly operational, contributing to lower performance indicators.

Cluster 1 – Medium-Traffic & Medium-Revenue Airports: Airports in this cluster maintain steady, mid-range operations, often serving as secondary hubs or regionally important airports. Their balanced traffic and revenue suggest operational stability without extensive scalability.

Cluster 2 – High-Traffic & High-Revenue Airports: This cluster includes major national and international hubs, such as Istanbul Airport, which demonstrate strong financial performance and operational intensity. These airports benefit from strategic geographic positioning, high connectivity, and commercial viability.

Cluster 3 – Seasonal or Specialized Airports: Characterized by operational or financial fluctuations, these airports often serve tourism-driven regions, such as Antalya or Muğla Dalaman, with noticeable seasonal peaks. In other cases, these may also include airports with fluctuating financial arrangements, such as those under Build-Operate-Transfer (BOT) models.

The use of the Elbow Method confirmed K=4 as the optimal number of clusters, ensuring an appropriate balance between granularity and generalization. The inclusion of both traffic and revenue dimensions enabled a comprehensive segmentation of airport profiles over time. The findings align with previous research emphasizing the utility of clustering methods in airport efficiency evaluations. For instance, Adler and Berechman (2001) used similar clustering and benchmarking approaches to differentiate airports based on traffic patterns and cost structures. Similarly, Barros and Peypoch (2009) applied cluster analysis to French airports, finding comparable categories of high-performing versus seasonal or underutilized airports. However, the current study differs from others in its temporal dimension using annual data over a seven-year period (2018–2024) and its inclusion of revenue types beyond aeronautical income, such as business and terminal services, offering a more financially nuanced classification. Furthermore, while Graham (2014) highlighted the limitations of one-time efficiency measures in assessing airport performance, this study incorporates year-over-year variability, allowing for temporal patterns to emerge in cluster assignments.

The clustering analysis offers several critical implications for both policymakers and airport managers.

Airports in Cluster 0 may require strategic subsidies or infrastructure investment to stimulate traffic and improve financial viability. Prioritizing regional development through connectivity incentives could help shift these airports into higher-performing categories.

Airports in Cluster 3, while financially viable during peak seasons, may benefit from diversification strategies, such as off-season charter services, conference tourism, or cargo development, to smooth out operational volatility.

Given the financial complexity of BOT-managed airports (frequently falling under Clusters 2 or 3), there is a need for transparent and adaptive regulation to ensure public interest alignment while promoting private sector efficiency.

Airports in Cluster 1 can serve as benchmarks for developing or restructuring other mid-sized airports, providing models for balanced operations in traffic handling, service quality, and commercial activity.

The methodology presented particularly the use of K-Means and multi-year analysis can be institutionalized by regulatory bodies such as DHMİ (State Airports Authority) for ongoing performance monitoring and strategic planning. The clustering results provide a valuable classification framework for Turkish airports, revealing distinct performance profiles influenced by traffic volumes, seasonal trends, and financial structures. By offering an empirical basis for strategic interventions, this analysis supports data-driven decision-making in national aviation policy and the operational management of airport infrastructure. The integration of clustering techniques with financial and operational data ensures a holistic understanding of airport efficiency, contributing to both academic research and practical governance in the civil aviation sector.

Table 6 examines the two primary airport ownership and operation models in Türkiye: the State-Owned Model (SOM) and the Build-Operate-Transfer (BOT) Model. The comparative evaluation aims to highlight differences in financing mechanisms, risk allocation, performance, and strategic outcomes, which are essential to understanding the airport ownership's operational and financial efficiencies.

Table 6. Comparative Analysis of State-Owned and BOT Airport Operation Models

Criteria	State-Owned Model (SOM)	Build-Operate-Transfer (BOT) Model
Ownership	Fully owned and managed by the government (DHMİ).	Infrastructure developed and temporarily managed by private investors under concession.
Financing Source	Funded through public budgets, state subsidies, and government loans.	Financed primarily by private sector capital and institutional investors.
Risk Distribution	Risks borne mainly by the public sector.	Risks (financial, operational, and demand-related) primarily borne by the private sector.
Revenue Streams	Limited to regulated fees and government-approved charges.	Includes diversified revenue (retail, parking, real estate, and service concessions).
Efficiency and Performance	Varies significantly; some airports operate efficiently, others suffer from underuse.	Generally more efficient due to performance incentives, innovation, and accountability.
Flexibility	Less flexible due to bureaucratic constraints and procurement procedures.	Greater flexibility in operations and investment decisions.
Public Accountability	High—aligned with national and social objectives.	Moderate—requires regulatory oversight to protect public interests.
Contract Duration	Permanent government control.	Time-bound concession agreements (e.g., 15–30 years).

Criteria	State-Owned Model (SOM)	Build-Operate-Transfer (BOT) Model
Technological Investment	Depends on public funding and political will.	Encouraged by competition and return-on-investment motives.
Examples in Türkiye	Adana, Trabzon, Erzurum, among others.	İstanbul, Antalya, İzmir, Ankara Esenboğa, Dalaman, Bodrum Milas.

Source(s): *DHMİ (2025), Wall & Wall (2013), Gillen (2011), Emek (2009), Graham (2014), and Oum et al. (2008).*

In Table 7, the cluster definitions are seperated into four sections as cluster 0, 1, 2, and 3 with their characteristics as minimal traffic and revenue, mid-range performing, high-traffic, and specialized airports including financial fluctiations.

Table 7. Cluster Definitions

Cluster	Characteristics
Cluster 0	Airports with minimal traffic and revenue (e.g., new or regional airports).
Cluster 1	Mid-range performing airports with balanced operations.
Cluster 2	High-traffic airports with extensive operations and revenue.
Cluster 3	Specialized airports or those with financial fluctuations.

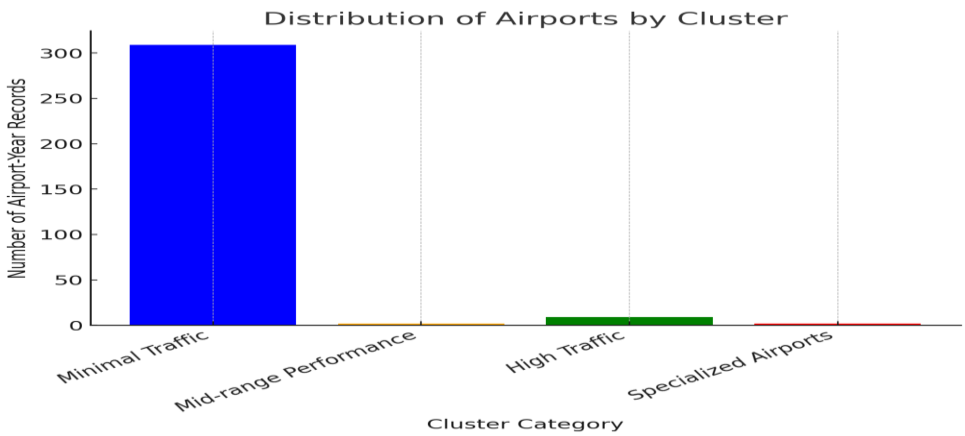

Figure 1. Distribution of Airport Clustering Analysis

Figure 1 illustrates the annual distribution of Turkish airports across four distinct clusters from 2018 to 2024, based on traffic and revenue data. Each cluster categorizes airports with similar financial and operational characteristics, with labels provided to identify individual airports within each group. The clustering reflects both temporal changes and structural differences in airport performance.

Cluster 0 – Minimal Traffic & Revenue Airports: This cluster includes primarily small regional or recently established airports characterized by limited passenger and aircraft traffic. These facilities typically operate on a smaller scale, serving niche domestic routes or airports in underdeveloped regions with restricted connectivity and economic activity.

Cluster 1 – Mid-Range Performing Airports: Airports in this cluster demonstrate moderate, stable levels of traffic and revenue. They often function as secondary hubs in larger cities or serve as national airports with balanced operations. The consistency in their performance suggests sustainable operations without significant seasonal or financial fluctuations.

Cluster 2 – High-Traffic & Revenue Airports: This cluster comprises Türkiye's largest and most commercially active airports. These facilities act as regional and international gateways, handling substantial volumes of passengers and flights. Their high revenue levels are supported by diversified commercial services, including retail, duty-free, premium lounges, and long-haul international routes.

Cluster 3 – Specialized or Fluctuating Airports: Airports in this group show non-linear traffic and revenue patterns. Many are seasonal or tourism-focused airports that experience peak activity during specific times of the year, particularly in the summer months. Others may serve niche markets or operate under unique financial arrangements that result in fluctuating performance profiles.

To sum up, Figure 1 provides a clear visual summary of the dynamic classification of Turkish airports over a seven-year period, offering insight into how different types of airports evolve under varying operational and economic conditions.

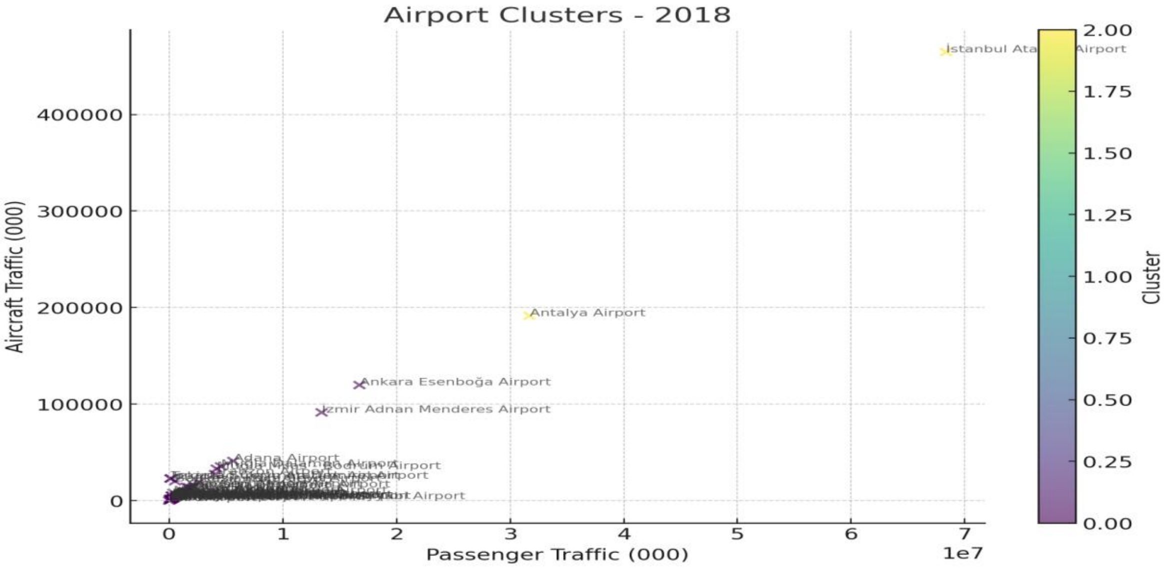

Figure 2. Cluster Interpretations – 2018

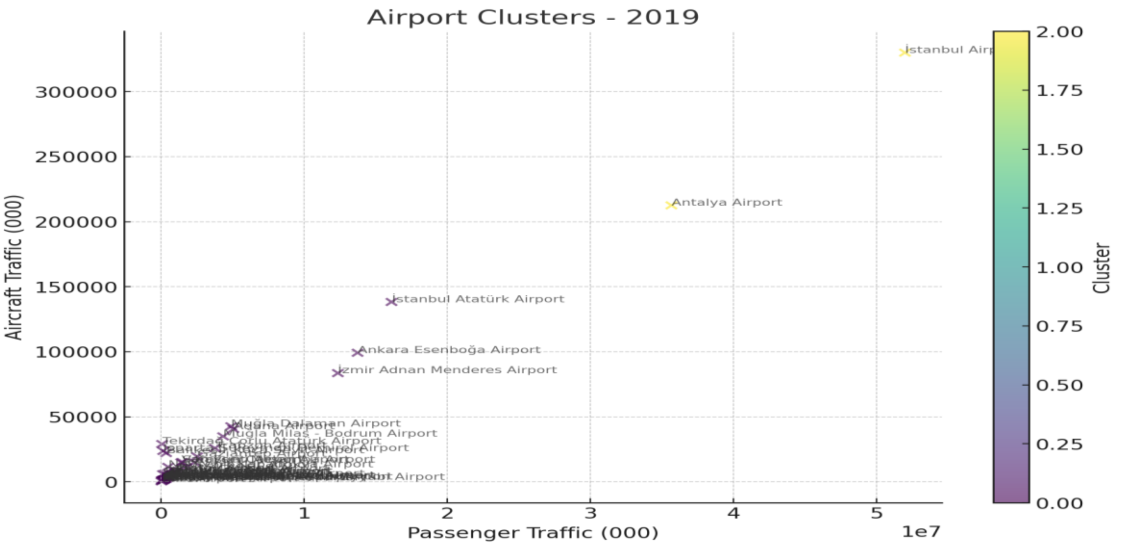

Figure 3. Cluster Interpretations - 2019

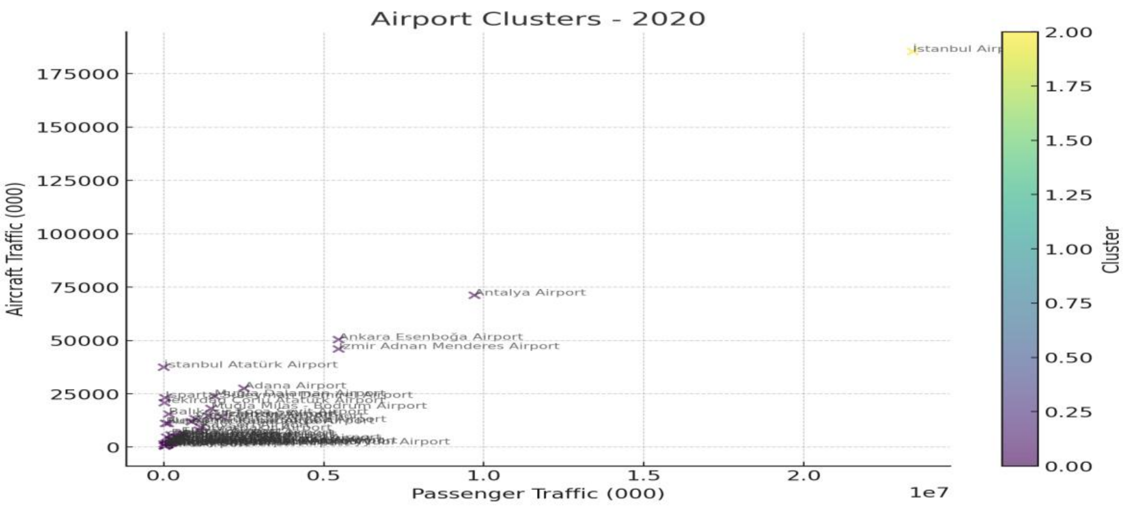

Figure 4. Cluster Interpretations – 2020

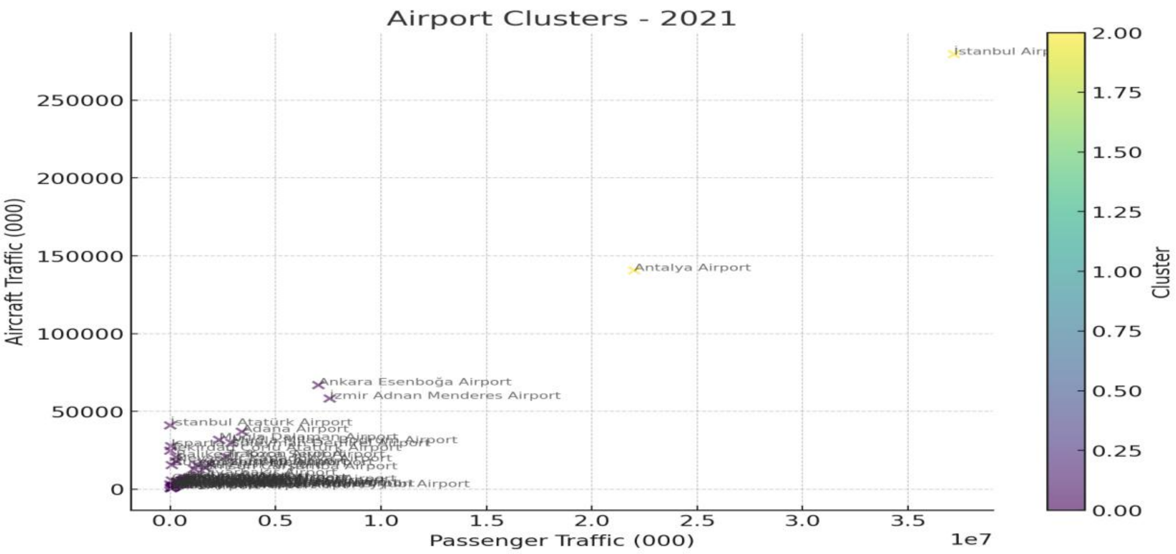

Figure 5. Cluster Interpretations – 2021

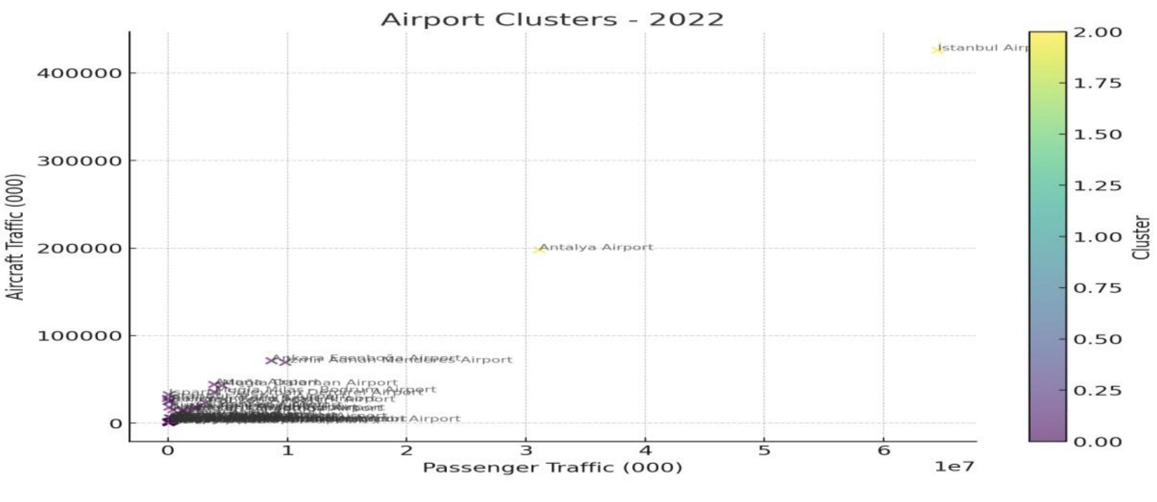

Figure 6. Cluster Interpretations – 2022

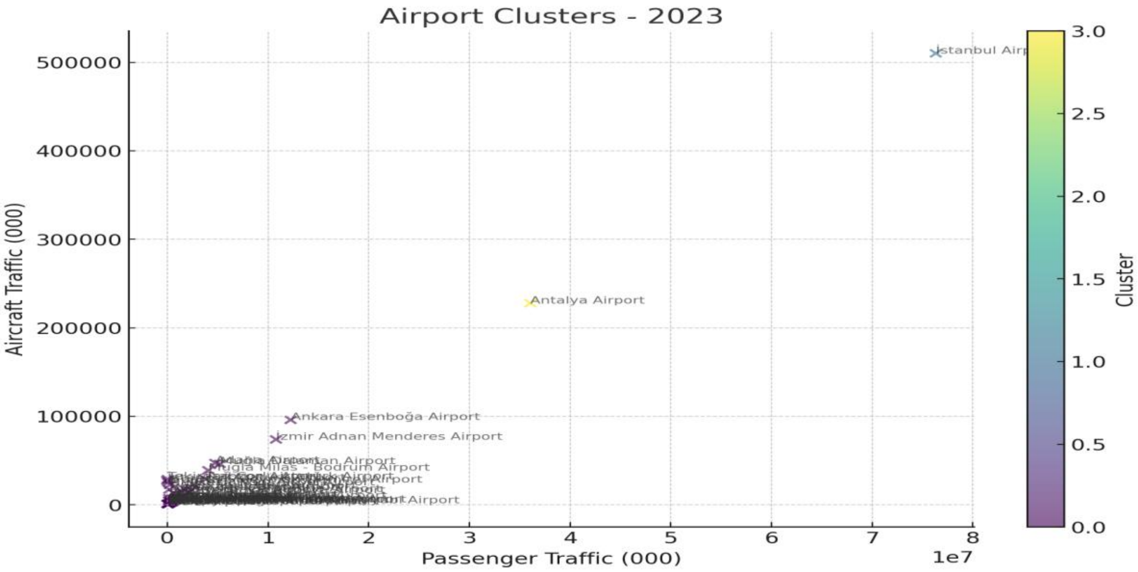

Figure 7. Cluster Interpretations – 2023

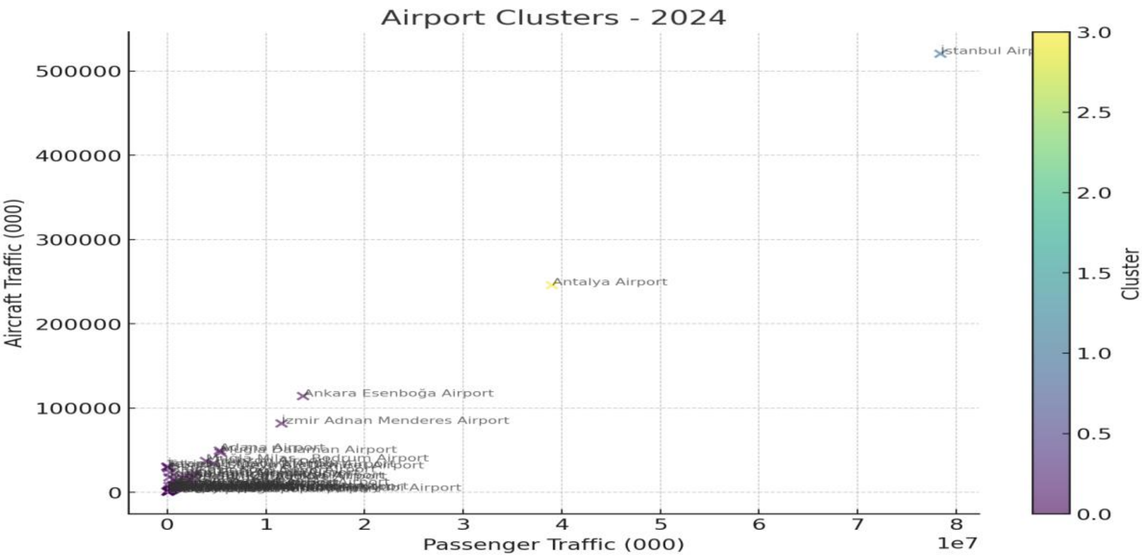

Figure 8. Cluster Interpretations – 2024

Between Figures 2 and 8, covering the years 2018 to 2024 (excluding 2020), several airports consistently appeared in Cluster 1, representing mid-range performing airports with balanced operations. These include Ankara Esenboğa Airport, Muğla Milas-Bodrum Airport, İzmir Adnan Menderes Airport, and Muğla Dalaman Airport are operated under the Build-Operate-Transfer (BOT) model alongside Adana Airport, Trabzon Airport, Isparta Süleyman Demirel Airport, Nevşehir Kapadokya Airport, and Erzurum Airport, which are managed under the State-Owned Model. The inclusion of these airports in Cluster 1 reflects their stable operational performance and ability to maintain moderate levels of passenger and aircraft traffic. In 2020, Erzurum Airport was the only one among this group excluded from Cluster 1. The exclusion is attributed to the adverse effects of the COVID-19 pandemic on winter tourism, which significantly impacted Erzurum's traffic volumes due to its status as a winter sports destination. This temporary decline differentiates Erzurum from the other Cluster 1 airports, which maintained more consistent traffic levels during that period.

In Figure 7 (2023) and Figure 8 (2024), notable changes occurred in the clustering of two major airports due to post-pandemic recovery trends. Istanbul Airport, having surpassed pre-COVID traffic volumes, was reclassified into Cluster 2 (High-Traffic & Revenue Airports), signifying its dominant role as a global hub. In contrast, Antalya Airport shifted to Cluster 3 (Specialized or Fluctuating Airports). This shift reflects Antalya's strong seasonal variation in passenger numbers, particularly between the summer tourism peak and the quieter winter months, distinguishing it from year-round high-traffic airports like Istanbul.

In Figure 1, Istanbul Atatürk Airport and Antalya Airport were both classified in Cluster 2, as Atatürk Airport operated at full capacity until its closure on 29 October 2018, after which Istanbul Airport gradually assumed its operations. Although Atatürk Airport never reached the 70 million passenger milestone achieved by Istanbul Airport in 2023–2024, its traffic levels in 2018 were sufficient to place it within the same high-performance cluster as Antalya.

Throughout the 2019 to 2022 period, Istanbul Airport remained in Cluster 2 alongside Antalya Airport, reflecting their similar scale and international connectivity. However, in 2023 and 2024, Istanbul Airport stood alone in Cluster 2, while Antalya Airport transitioned to Cluster 3 due to seasonal variability in air traffic. Among other BOT airports as Ankara Esenboğa, Muğla Milas-Bodrum, İzmir Adnan Menderes, and Muğla Dalaman in Cluster 1 remained consistent, signifying their stable, mid-level operational performance.

Unlike the 38 remaining state-owned airports, five non-BOT model airports Adana, Trabzon, Isparta Süleyman Demirel, Nevşehir Kapadokya, and Erzurum (except in 2020) consistently performed at Cluster 1 levels. Their continued success in leveraging geographic advantages and sustaining operations without BOT investment structures illustrates their effective role in Türkiye's regional aviation network. In contrast, the following 39 state-owned regional airports were consistently grouped under Cluster 0 (Minimal Traffic & Revenue Airports):

Adıyaman, Ağrı Ahmed-i Hani, Amasya Merzifon, Balıkesir Koca Seyit, Balıkesir Merkez, Batman, Bingöl, Bursa Yenişehir, Çanakkale, Çanakkale Gökçeada, Denizli Çardak, Diyarbakır, Elazığ, Erzincan, Gaziantep, Hakkâri Yüksekova Selahaddin Eyyubi, Hatay, Iğdır Şehit Bülent Aydın, Kahramanmaraş, Kastamonu, Kars Harakani, Kayseri, Kocaeli Cengiz Topel, Konya, Malatya, Mardin, Muş, Ordu Giresun, Samsun Çarşamba, Siirt, Sinop, Sivas Nuri Demirağ, Şanlıurfa GAP, Şırnak Şerafettin Elçi, Tekirdağ Çorlu Atatürk, Tokat, Uşak, and Van Ferit Melen.

These airports were characterized by low traffic volumes, minimal commercial revenues, and underutilized infrastructure, which discouraged private sector participation through BOT arrangements. Unlike the more successful Cluster 1 airports, these facilities struggled to capitalize on their geographic positioning, indicating limited regional demand, operational constraints, or insufficient strategic development.

7. DISCUSSION AND CONCLUSION

This study aimed to compare State-Owned (without privatization) and Build-Operate-Transfer (BOT) model airports in Türkiye using Clustering Analysis to assess financial and operational efficiencies. The research explored the impact of airport ownership structures on key performance indicators including, passenger traffic, aircraft movements, revenue streams from navigational, terminal, and business services. The introduction section established the significance of airports as economic infrastructure, emphasizing Türkiye's rapid aviation sector growth. With air passenger traffic exceeding 230 million in 2024, Türkiye ranked first in Europe and sixth worldwide in passenger volume. The study highlighted the increasing privatization trend, where BOT-model airports played a crucial role in accommodating the growth of air traffic demand. The literature review section reinforced the importance of efficiency assessment in airport operations. It explored different airport ownership models worldwide and their economic impacts, particularly the advantages and challenges of privatization through the BOT model. Research indicated that private sector involvement often enhances financial sustainability, but requires careful regulatory oversight to ensure service quality and public interest alignment. The data and methodology section detailed the selection of state-owned and BOT-model airports applied K-Means Clustering Analysis to categorize them into four clusters based on financial and operational efficiency. The methodology ensured a robust analysis by standardizing financial data (revenue streams) and operational data (traffic volumes) while determining the optimal number of clusters through the Elbow Method (K=4).

High-Traffic & High-Revenue Airports with BOT Model (like Istanbul Airport since 2019 and İstanbul Atatürk Airport in 2018) perform significantly better due to their global connectivity, commercial revenue streams, and infrastructure investments.

Seasonal High-Traffic & High-Revenue Airports with BOT Model (like Antalya Airport) perform significantly better especially in summer season, making high revenues from tourists.

Medium-Traffic & Medium-Revenue Airports with BOT Model (like Ankara Esenboğa, Izmir Adnan Menderes) maintain sustainable financial and operational performance but face moderate growth limitations. Muğla Dalaman, and Muğla Milas-Bodrum Airports are tkaen place in this list due to high population and summer season attractiveness for tourists.

Medium-Traffic & Medium-Revenue Airports with State-Owned Model (without privatization) like Adana Airport, Trabzon Airport, Isparta Süleyman Demirel Airport, Nevşehir Kapadokya Airport, and Erzurum Airport. These airports are active in operation by making revenues for the country's economy in relatively good levels.

Low-Traffic & Low-Revenue Airports (like other 38 airports) struggle with financial sustainability and rely heavily on state funding because of low level operations.

When compared with previous studies in the literature, the findings of this research reveal both significant similarities and notable differences. Consistent with prior research, airports operated under the Build-Operate-Transfer (BOT) model generally show superior financial sustainability and operational efficiency, particularly due to their commercialized structures, infrastructure investments, and global connectivity. High-traffic airports such as Istanbul and Antalya exemplify this trend, aligning with the widely acknowledged advantages of privatization. However, a key distinction identified in this study is that several state-owned airports such as Adana and Trabzon also demonstrate relatively strong performance about revenue generation and traffic volumes, challenging the prevailing narrative that publicly operated airports consistently underperform. Moreover, the application of K-Means Clustering Analysis in this study provides a more nuanced and multidimensional segmentation of airport efficiency compared to traditional, single-metric evaluations often found in earlier works. In summary, while this study supports the general consensus in the literature regarding the benefits of the BOT model, it contributes novel insights by highlighting the potential of well-managed state-owned airports and offering a robust, data-driven framework for evaluating airport performance in Türkiye.

According to the information about the comparison of findings with the connected studies' similarities and differences. The findings highlight the importance of strategic privatization in improving airport efficiency by confirming airport ownership models that significantly influence financial and operational efficiency. However, policymakers must ensure that public-private partnerships (PPP) are structured to balance profitability with public service obligations. The clustering results revealed that BOT-model airports generally performed better in revenue generation due to their commercialized operations, improved infrastructure, and service-oriented approach. Meanwhile, state-owned airports displayed varied efficiency levels, with some performing comparably to BOT airports while others struggled with financial sustainability due to regulatory and bureaucratic constraints. While BOT model airports showed higher revenue generation and traffic capacity, state-owned airports displayed mixed performance. Some state-owned airports operated efficiently, but others faced financial constraints, infrastructure limitations, or lower traffic volumes. The clustering analysis, structured into four stages, provided insightful segmentation of airports.

Data Preprocessing: Cleaning and standardizing revenue and traffic data for accurate analysis.
Feature Selection & Normalization: Identifying financial and operational parameters while ensuring comparability.
Optimal Cluster Determination: Using the Elbow Method to define K=4 clusters.
Cluster Interpretation: Categorizing airports based on their financial and operational efficiency patterns.

These insights offer valuable implications for policy-makers, airport authorities, and private investors. State-owned airports with low efficiency should adopt privatization strategies or restructuring measures to enhance performance. BOT model airports have demonstrated financial success but require regulatory oversight to balance profitability with public service obligations. In conclusion, privatization through the BOT model has proven effective in maximizing airport performance, though state-owned airports can still achieve efficiency with proper management reforms and investment strategies.

Future airport development strategies should integrate data-driven decision-making to optimize investment, infrastructure expansion and operational efficiency, using hybrid financing models, AI-driven operational efficiency and sustainability-driven investment strategies. This study serves as a foundation for future academic research in airport management, transportation economics, and privatization strategies, offering a quantitative and managerial perspective on the evolving airport ownership landscape. Clustering Analysis remains a valuable tool in identifying airport performance patterns, guiding strategic infrastructure investments and aviation policy planning in Türkiye and globally.

REFERENCES

Adler, N., & Berechman, J. (2001). Measuring airport quality from the airlines' viewpoint: an application of data envelopment analysis. *Transport policy, 8*(3), 171-181. https://doi.org/10.1016/S0967-070X(01)00011-7

Adler, N., & Golany, B. (2001). Evaluation of deregulated airline networks using data envelopment analysis combined with principal component analysis with an application to Western Europe. *European Journal of Operational Research, 132*(2), 260-273. https://doi.org/10.1016/S0377-2217(00)00150-8

Ahmed, M., Seraj, R., & Islam, S. M. S. (2020). The k-means algorithm: A comprehensive survey and performance evaluation. *Electronics*, *9*(8), 1295. https://doi.org/10.3390/electronics9081295

Airbus. (2013). *Airbus GMF Booklet 2013-2032. (Blagnac Cedec, France).* Retrieved March 31 2024 from https://www.airbus.com/sites/g/files/jlcbta136/files/2021-07/B-Lange-Global-Market-Forecast.pdf

Bao, D., & Hua, S. (2017). Flight time and frequency-optimization model for multiairport system operation. *Mathematical Problems in Engineering*, *2017*(1), 7371461. https://doi.org/10.1155/2017/7371461

Boeing. (2013). *Boeing Current Market Outlook 2013. (Seattle, USA).* Retrieved March 31 2024 from https://www.iaa.ie/docs/default-source/misc/boeing_current_market_outlook_20131.pdf

Chen, C. C. F., & Schonfeld, P. (2024). Optimal clustering analysis for airport parking. Journal of Air Transport Management, 120, 102659. https://doi.org/10.1016/j.jairtraman.2024.102659

Cohen, J. P., & Paul, C. J. M. (2003). Airport infrastructure spillovers in a network system. *Journal of Urban Economics, 54*(3), 459-473. https://doi.org/10.1016/j.jue.2003.06.002

Commission of the European Communities. (2004). Green paper on public-private partnerships and community law on public contracts and concessions. Office for Official Publications of the European Communities. Retrieved 10 May 2024 from https://op.europa.eu/en/publication-detail/-/publication/94a3f02f-ab6a-47ed-b6b2-7de60830625e/language-en

Devlet Hava Meydanları İşletmesi (DHMİ). (2025). Retrieved 20 April 2025 from www.dhmi.gov.tr

Devlet Hava Meydanları İşletmesi (DHMİ). (2025). Retrieved 20 April 2025 from www.dhmi.gov.tr/havaalanlari.aspx

Devlet Hava Meydanları İşletmesi (DHMİ). (2025). *Statistics year, General Directorate of State Airports Authority statistical reports.* Retrieved 30 April 2025 from https://www.dhmi.gov.tr/FinansalDurumDosya/2025%20B%C3%BCt%C3%A7e%20Kitab%C4%B1%2023.12.19.pdf

Devlet Hava Meydanları İşletmesi (DHMİ). (2025). *Statistics year, General Directorate of State Airports Authority statistical reports.* Retrieved 30 April 2025 from https://www.dhmi.gov.tr/Lists/FaaliyetRaporlari/Attachments/20/49453_1_DHMI2019FaaliyetRaporu(pdf)_FaaliyetRaporu_2019webformati.pdf

Dožić, S. (2019). Multi-criteria decision making methods: Application in the aviation industry. *Journal of Air Transport Management*, *79*, 101683. https://doi.org/10.1016/j.jairtraman.2019.101683

Emek, U. (2009). Karşılaştırmalı perspektiften kamu özel işbirlikleri: Avrupa Topluluğu ve Türkiye. *Rekabet Dergisi, 10*(1), 7-53.

Fageda, X., & Flores-Fillol, R. (2012). On the optimal distribution of traffic of network airlines. *European Economic Review, 56*(6), 1164-1179. https://doi.org/10.1016/j.euroecorev.2012.05.001

Gallagher, R., & Jona, L. (2019). *Europe's new digital lie detector.* Retrieved 10 February 2024 from https://theintercept.com/2019/07/26/europe-border-control-ai-lie-detector/

Gao, Y. (2021). What is the busiest time at an airport? Clustering US hub airports based on passenger movements. *Journal of Transport Geography, 90,* 102931. https://doi.org/10.1016/j.jtrangeo.2020.102931

Gillen, D. (2011). The evolution of airport ownership and governance. *Journal of Air Transport Management, 17*(1), 3-13. https://doi.org/10.1016/j.jairtraman.2010.10.003

Graham, A. (2014). Sustainability and the small airport. In *Seventh International Forum on Shipping, Ports and Airports (IFSPA).*

Güner, S., & Gülay, İ. (2018). Havalimanı işletmeciliği ve Türkiye'de havalimanlarının mülkiyet yapısı. *Ulakbilge, 6*(29), 1327-1348.

Hamzawi, S. G. (1992). Lack of airport capacity: Exploration of alternative solutions. *Transportation Research Part A: Policy and Practice, 26*(1), 47-58. https://doi.org/10.1016/0965-8564(92)90044-8

Ida, N., & Tamura, T. (2005). Effects of deregulation on local air passenger demand. Research in *Transportation Economics, 13,* 211-231. https://doi.org/10.1016/S0739-8859(05)13010-8

International Civil Aviation Organization (ICAO). (2025). Retrieved 28 April 2025 from https://www.icao.int/sustainability/Documents/RTK%20ranking/International%20Total%20RTK%20Rankings_2025_SIDS_LDC_LLDC.PDF

Itani, N., O'Connell, J. F., & Mason, K. (2015). Towards realizing best-in-class civil aviation strategy scenarios. *Transport Policy, 43,* 42-54. https://doi.org/10.1016/j.tranpol.2015.05.013

Kupfer, F., Kessels, R., Goos, P., Van de Voorde, E., & Verhetsel, A. (2016). The origin–destination airport choice for all-cargo aircraft operations in Europe. *Transportation Research Part E: Logistics and Transportation Review*, *87*, 53-74. https://doi.org/10.1016/j.tre.2015.11.013

Oum, T. H., Yan, J., & Yu, C. (2008). Ownership forms matter for airport efficiency: A stochastic frontier investigation of worldwide airports. *Journal of urban economics, 64*(2), 422-435. https://doi.org/10.1016/j.jue.2008.03.001

Leading Edge Aviation Planning Professionals (LEAPP). (2001). *Restructuring of civil aviation administration.* Global Aviation Planning and Management Consulting Company. Retrieved 05 April 2024 from https://www.airport-technology.com/contractors/design/leapp/

Lijesen, M. G., Nijkamp, P., & Rietveld, P. (2002). Measuring competition in civil aviation. *Journal of Air Transport Management, 8*(3), 189-197. https://doi.org/10.1016/S0969-6997(01)00048-5

Lin, L., Chen, G., Liu, X., Liu, X., & Zhang, T. (2023). Characterizing cooling load in multi-area airport terminal buildings: Clustering and uncertainty analysis for energy flexibility. *Journal of Building Engineering, 79,* 107797. https://doi.org/10.1016/j.jobe.2023.107797

Madas, M. A., & Zografos, K. G. (2008). Airport capacity vs. demand: mismatch or mismanagement?. *Transportation Research Part A: Policy and Practice, 42*(1), 203-226. https://doi.org/10.1016/j.tra.2007.08.002

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. https://doi.org/10.1016/j.tranpol.2016.02.008

Pham, D., Asano, S., Bolliger, M., Day, M. N., Hofstee, H. P., Johns, C., ... & Yazawa, K. (2005, February). The design and implementation of a first-generation CELL processor. In *ISSCC. 2005 IEEE International Digest of Technical Papers. Solid-State Circuits Conference, 2005.* (pp. 184-592). IEEE. https://doi.org/10.1109/ISSCC.2005.1493930

Türkiye İstatistik Kurumu (TUİK). (2025). Retrieved March 03 2025 from https://data.tuik.gov.tr/Kategori/GetKategori?p=ulastirma-ve-haberlesme-112&dil=1

Türkiye'deki Uluslararası Havalimanları ve Kodları. (2025). Retrieved 26 April 2025 from https://www. turkiye-uluslararasi-havalimanlari

Wall, A., & Wall, T. (2013). *Public-private partnerships in the USA: Lessons to be learned for the United Kingdom.* Routledge.

Yalçın, F. C. (2014). *Kamu özel işbirliği ve özelleştirme: kavramsal bir çerçeve.* İstanbul Ticaret Üniversitesi Yayınları

Yalcin, S., & Ayyildiz, E. (2018). Analysis of airports using clustering methods: case study in Turkey. *Journal of Management Marketing and Logistics, 5*(3), 194-205. http://doi.org/10.17261/Pressacademia.2018.963

Yerlikaya, G. K. (2002). *Yap-işlet-devret modeli hukuki mahiyeti ve vergilendirme.* Seçkin Yayıncılık