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A NOVEL HYBRID TFMEREC–ARAS MCDM APPROACH FOR EVALUATING THE PERFORMANCE OF GLOBAL AIRPORTS

Gül Alışar Kayar[1*], İlker İbrahim Avşar[2]

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[1] Toros University, Faculty of Economics, Administrative and Social Sciences, Department of International Trade and Logistics, Mersin, Turkiye

[2] Osmaniye Korkut Ata, Bahce Vocational School, Department of Logistics, Osmaniye, Turkiye

[*]**Corresponding Author:**
Gül Alışar Kayar

Email:
gul.alisar@toros.edu.tr

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ABSTRACT

In today's world, airports are much more than just transportation hubs. Globalization, technological advancements, and increasing competition have transformed them into strategic centers for planning and development. This transformation necessitates effective resource management, continuous performance improvement, and a robust commitment to achieving sustainable development goals. In this context, scientific research is crucial for improving the operational, environmental, and social sustainability of airports. This study evaluated 20 airports using a novel hybrid multi-criteria decision-making (MCDM) approach called TFMEREC-ARAS, based on 11 different criteria. The analysis identified Bahrain International Airport, Singapore Changi Airport, and Narita International Airport as the three highest-performing airports. These airports achieved strong results in both passenger service and environmental sustainability, clearly demonstrating excellence in operational effectiveness, passenger satisfaction, and overall management quality. The findings underscore the importance of multidimensional performance assessment in airport management, providing valuable insights to practitioners for informed strategic decision-making processes. At the same time, the research contributes to the literature by demonstrating the applicability of the TFMEREC-ARAS method to airport performance analysis. By introducing this hybrid method in this context, the study presents an innovative and valuable framework for future studies, offering practical guidance for airport managers seeking to balance performance, sustainability, and competitiveness.

Keywords: *Airport, multi-criteria decision-making, TFMEREC, ARAS*

1. INTRODUCTION

In recent years, managers have recognised the importance of airports as a key economic driver on a global scale. The aviation sector offers rapid global transportation and generates substantial employment opportunities. Given this critical role, airports must be managed effectively and sustainably. Assessing their economic efficiency is also strategically important for businesses. This is the only way to remain competitive within the industry (Kucukvar et al., 2021).

As the study by Mahesh and Calvert demonstrates, there has been a recent surge in interest among scholars in logistics and airport-related issues (Mahesh and Calvert, 2025). The main reason for this is the significant growth of airports. In this context, airports have become a key research area, and scientific studies play an important role in addressing related challenges. Indeed, Duliński emphasises the necessity of determining optimal airport strategies, stating that this can only be achieved through scientific research specific to individual airports (Duliński, 2025). In the context of globalisation, airports must continuously improve their performance in an intensely competitive environment. Rapid developments in transportation technologies also mean that airports must undergo continuous transformation (Gechev, 2025). The main objective of efficient airport management is therefore to ensure sustainable improvement by using available resources as effectively as possible (Ersoy, 2021).

Mızrak et al. argue that sustainability is a key factor in airport competitiveness (Mızrak et al., 2024). In this context, studies that employ multi-criteria decision-making (MCDM) methods are essential for evaluating and improving airport sustainability. Notably, the studies of X. Jia et al. offer valuable insights into the future of the sector. Airports are an integral part of transport infrastructure and an indispensable element of modern life (Jia et al., 2023). Therefore, their sustainable development is crucial for the modern world (Turskis et al., 2019). Greer et al. emphasise the importance of using measurable indicators when evaluating airports (Greer et al., 2020).

Airports can sometimes experience various issues, particularly regarding security. Security criteria are essential for the operational efficiency of airports (Ergün, 2018). Therefore, airport operators must address these issues effectively. In this context, the potential of advanced technologies, such as artificial intelligence, should not be overlooked (Drakul, 2025). The quality of airport services is a key factor that directly affects efficiency (Phu, 2025). Advanced technologies such as artificial intelligence can significantly enhance this service quality (Macit, 2025). However, security vulnerabilities and operational risks at airports can pose serious problems for businesses (Noah, 2025). Therefore, assessing these issues is critical to understanding the current state of the industry (Thangaraju & Palani, 2025). The data obtained can help industry representatives make more informed and effective decisions. To achieve this, airports should be evaluated using MCDM methods within a specified framework (Özdemir, 2024). This study ranked airports using the MCDM approach. The novelty of this research lies in the fact that performance variables presented by Skytrax were tested for the first time using the expanded HYBRID TFMEREC–ARAS MCDM method. This contributes to filling an important gap in literature. Furthermore, the research provides industry representatives with a comprehensive overview of the airports examined in accordance with the defined criteria. This is also crucial for the future development of the industry.

Moreover, scientific studies that evaluate airports based on measurable criteria are of strategic importance to both practitioners and academics. These studies help develop objective tools to enhance infrastructure efficiency, improve service quality, and increase user satisfaction. MCDM methods enable a comprehensive analysis of airport performance from different perspectives. They support informed decisions on resources, investments, and operations. Standardised assessments enable global comparisons and enhance competitiveness. This promotes sustainability, innovation, and environmental progress. Scientifically based analyses provide practical benefits and contribute to academic literature, paving the way for new areas of research.

In summary, this research project aims to evaluate airport performance by integrating operational, environmental, and social factors using a novel, hybrid MCDM approach known as TFMEREC-ARAS. This study is important because it addresses the growing need for sustainable, strategic airport management. Airports now serve as global development hubs rather than merely transport nodes. By assessing 20 airports against 11 criteria, the study identifies high-performing examples and provides practitioners seeking data-driven strategies with valuable insights. This study is the first to apply TFMEREC-ARAS to analyse airport performance using this dataset, offering methodological innovation and laying the groundwork for future comparative research.

2. LITERATURE

The focus of academic studies on airports varies depending on the researcher's discipline and perspective. These studies inform the analysis of the current situation for airport businesses and contribute to it. They also help aviation sector managers develop healthier strategic plans for the future.

For example, forecasting applications developed for the aviation sector can predict trends and provide managers with valuable insights to inform strategic decision-making. Secondly, optimising gate allocation processes at airports can enhance passenger satisfaction. Thirdly, efficient aircraft fuel planning is a key area of research that improves operational efficiency. Finally, identifying connection points in airport network structures is essential for ensuring the efficiency and continuity of the transport network (Rassu et al., 2025; Jia et al, 2025; Zampirolli and Amaral, 2025; Ren et al., 2025). In this context, this chapter discusses general and methodological research trends relating to airports. The reviewed studies provide an overview of the aviation sector and highlight its developments.

2. 1. AIRPORT RESEARCH

The efficiency of airports is affected by various factors. Even in car-dependent countries like Qatar, public transport investment is vital for airport efficiency. Although local passengers may not use public transport frequently, it should still be offered as an alternative for international passengers (Zaidan and Abulibdeh, 2018). In addition to metro connections, many other factors affect customer satisfaction at airports. Clean terminal areas are one of the most important of these. The presence of commercial areas, such as duty-free shops, enhances passenger experience and generates interest. The quality and efficiency of terminal services, passport and immigration procedures, staff behaviour, and time management also directly impact passenger satisfaction. Global airport operators must address operational challenges, including long queues, complex security procedures, excessive waiting times, inadequate signage, and flight delays (Bae and Chi, 2021). Industry 4.0 accelerates airport digitalization by integrating smart machines, sensors, and software to boost computing power. However, the environmental impact of this process must not be overlooked. Airport digitalisation should be evaluated using a holistic approach that considers technological, environmental, and economic factors (Kucukvar et al., 2021).

In some cases, expanding airports can improve efficiency. Tokyo International Airport (Haneda Airport), for example, is a central domestic hub in Japan. The airport is being expanded due to increasing demand. This is because it is a popular hub for both domestic and international flights (Watabe and Noguchi, 2011). Cost is also an important factor for airports. The demand for air travel is expected to increase worldwide in the coming years. Alongside this growth, maintaining low operating costs has become a strategic imperative for airlines. This will enable airports to expand by offering low-cost alternatives. Increased demand will also encourage airports to restructure and diversify their business models (Inoue et al., 2015).

2. 1. 1. BAHRAIN INTERNATIONAL AIRPORT – BAH

A wealth of research on airports is available in scientific literature. This section discusses the major airports analysed in this study. Bahrain International Airport is the highest-performing airport in line with the established criteria. This airport is a key component of the regional air transport network, handling a substantial share of long-haul international traffic. As a strategic transit hub between Asia and Europe, it plays a vital role in managing regional passenger and cargo movements efficiently (Towfiqi, 2018).

2. 1. 2. SINGAPORE CHANGI AIRPORT - SIN

Singapore Changi is vital to Asia-Pacific flow management due to its high share of long-haul traffic (Schultz et al., 2021). Meanwhile, Lee et al. examined the effectiveness of self-service check-in counters and concluded that they are efficient (Lee et al., 2014). Wu and Tsui identify Changi as one of the world's busiest airports (Wu and Tsui, 2020). The authors emphasize the "Changi Rewards" app's positive effects on passenger experience and commercial potential.

Chutiphongdech and Phengkona state that non-aviation businesses increasingly use events as a marketing strategy (Chutiphongdech and Phengkona, 2024). Airport managers organise cultural and sporting activities to attract tourists and enhance the airport's appeal. This approach has fostered the image of airports as vibrant and engaging spaces. Finally, Kim et al. (2025) discuss the digital transformation process implemented at Singapore Changi Airport (Kim et al., 2025). The authors note that smart, contactless systems have been adopted, offering key advantages for modern airport management.

2. 1. 3. NARITA INTERNATIONAL AIRPORT – NRT

Narita Airport plays a critical role in Japan's international air traffic. Although the airport is far from the city center, its efficient rail connections help minimize accessibility issues related to time and cost. Narita is Japan's main global hub, especially for long-haul international flights. (Feldhoff, 2003).

This airport serves as a strategic hub, acting as Tokyo's primary intercontinental gateway. Its long-haul network makes it a key hub for Japan and East Asian air traffic. These structural features contribute to Narita's high-performance ranking (Miyamoto, 2022).

2. 2. RESEARCH ON METHODOLOGY

2. 2. 1. MCDM METHOD

The MCDM method ensures that alternatives are ranked according to specified criteria. These rankings are based on the weighting of the criteria, which experts primarily determine. For instance, Šarić and Abramović (2025) evaluated the process of connecting airlines to railways using 17 such criteria. These criteria fall under four main categories: traffic, availability, finances, and the environment (Šarić and Abramović, 2025). As can be seen, the MCDM method involves evaluating alternatives within a framework of criteria determined by the researcher. Therefore, the selected criteria are fundamental to determining the scope and direction of the research.

As illustrated above, the MCDM method involves ranking alternatives according to specified criteria. In this respect, it is an effective model for comparing and ranking alternatives within a given set of criteria. This means it can be applied in many different fields. However, regardless of the field in which it is used, the criteria must first be appropriately weighted to enable ranking of the alternatives. Selecting the alternatives and criteria is fundamental to determining the scope, direction, and application area of the research. In this context, researchers' reliance on expert opinions when determining the criteria is crucial for ensuring the method's reliability and validity (Klarić, et al., 2025; Worku, 2025; Zandi and Lotfata, 2025; Tighnavard Balasbaneh et al., 2025).

2. 2. 2. THE USE OF MCDM METHODS IN AIRPORT PROBLEMS

Evaluations of airports based on efficiency and other criteria have received attention in academic circles (Lu et al., 2019). MCDM methods are among the approaches used in such evaluations (Shen et al., 2019; Merdivenci et al., 2021). In this context, studies that use MCDM methods for various purposes are of interest:

- An effective partnership between airline and airport operations can be identified using MCDM methods. These factors can then be used to select the most suitable airports for airlines (Tunčikienė and Katinas, 2020).

- Renewable energy models can be developed for airports. These models determine the optimal solution by striking the right balance between different renewable energy options (Jia et al., 2021).
- Successful airport planning can be modelled within a framework of criteria. MCDM methods reveal that international integration is a critical planning criterion, providing planners with valuable insights (Liou et al., 2018).
- The attributes influencing airport density can be identified. In this context, security services are considered an important factor (Bongo and Ocampo, 2018).
- Airport service quality can be measured and compared using multi-criteria evaluation approaches (Chien-Chang, 2012).
- Airport sustainability can be analysed in terms of capacity-demand matching. Such assessments play a critical role in infrastructure planning (Janic, 2015).

Pishdar et al. evaluated the airports using a combination of the BWM and MACBETH methods (Pishdar et al., 2019). The evaluation process was based on five criteria. The main objective of the research was to analyse the airports and determine the most suitable hub. This would allow the most suitable airport to be identified as a central transit point for passengers travelling through multiple airports. According to the study's results, the best 'hub' airport in Iran is the one with the ICAO code "OIBK", which is affiliated with the International Civil Aviation Organization (ICAO).

Pandey identified the strategic design parameters of low-cost airlines, which have gained popularity in recent years (Pandey, 2020). The study employed the fuzzy MCDM method. Furthermore, a HoQ analysis was conducted to determine the technical criteria that constitute the strategic design parameters of an airport. The research findings reveal that Don Mueang Airport requires small-scale improvements in certain areas.

Sumerli Sarigul et al. evaluated the quality of airport services using MCDM methods (Sumerli Sarigul et al., 2023). The criteria weights were determined using MEREC, an objective weighting method. The MARCOS and CoCoSo methods were then employed to rank the alternatives based on these criteria. The study included 17 five-star airports, as defined by the 2021 Skytrax database. The evaluation criteria consisted of terminal comfort, transportation services, security screening, immigration services, arrival and departure services, directional signage, services for transferring passengers, terminal amenities, shopping facilities, and food and beverage services. The MEREC analysis revealed that immigration services were the most effective criterion. The overall evaluation concluded that Chubu Centrair Airport had the highest service quality.

Liou et al. analysed airports using the DEMATEL and ISM methods (Liou et al., 2024). The Delphi technique was employed to determine the study's criteria. These criteria were developed in consultation with a panel of experts comprising airport managers and relevant management authorities. In the evaluation process, 12 criteria related to the operational and financial impact of the pandemic were considered. The study's main objective is to examine the impact of the pandemic on airport services. According to the analysis results, requiring a vaccination certificate for entry into a country has the greatest impact on airport performance. In operational terms, aircraft movements were identified as a key criterion. The findings reveal that these two criteria have a significant impact on airports' net revenue.

Kalan et al. employed a combination of AHP, ELECTRE, and MOORA method to determine the optimal location for a hub airport (Kalan et al., 2024). Various criteria were used to evaluate airports in Türkiye, including operating capacity, costs, terminal and apron facilities, geographical location, passenger transportation services, and demand in the service area. These criteria were ordered by priority based on expert opinions, with the weighting of each criterion calculated using the AHP method. According to the ELECTRE method, which was used to evaluate the alternatives, Antalya Airport was identified as the most suitable hub airport. However, the MOORA method indicates that New Çukurova Airport is the best option. Both methods show that these two airports are the top two choices. This demonstrates that different MCDM methods produce different prioritisation structures, the results of which are complementary.

2. 2. 3. USING MEREC/TFMEREC AND ARAS IN AIRPORT PROBLEMS

The MEREC method is widely used in literature as an objective approach to criteria weighting in decision-making processes. For instance, the MEREC method is favoured for criteria weighting in the context of increasing airport capacity in the Lisbon region (Ferreira et al., 2024). In addition, Deniz demonstrated the potential application of multi-criteria decision-making techniques in this field by evaluating the sustainable aviation industry using the ARAS method (Deniz, 2024).

This study uses the TFMEREC method, as defined by Hasnan et al., to allocate weights to criteria for supplier selection (Hasnan et al., 2024). According to the researchers, TFMEREC provides decision-makers with more accurate weights, enabling them to make more informed and effective decisions. This method is also recommended because it effectively addresses the uncertainties encountered in multi-criteria decision-making processes. Its flexibility makes it ideal for handling uncertainty and subjective judgments.

2. 2. 4. CONTRIBUTION OF THIS RESEARCH

The above studies demonstrate the widespread use of MCDM methods to evaluate airports based on factors such as service quality, sustainability, location selection, and infrastructure planning. Most of these studies rely on well-established techniques, including the AHP, DEMATEL, ELECTRE, and MARCOS. Adopting a new MCDM approach in this context is therefore an important step forward. This increases the diversity of methods used in literature and improves both academic understanding and practical decision-making when analysing airport performance. This study introduces a recently developed method and demonstrates its potential to provide richer, more reliable insights. Accordingly, it not only fills a research gap but also lays the groundwork for future applications in aviation research.

3. METHODOLOGY

Decision-making is a core human activity that has been extensively studied since the mid-20th century. It now plays a central role in economics and management (Liu and Xu, 2021). Decision-making can be defined as determining the most appropriate alternative based on specific criteria. Conflicts between criteria complicate the decision-making process. A balance must be achieved between the criteria. MCDM facilitates decision-making by achieving this balance through mathematical models. MCDM methods help decision makers prioritise options when dealing with multiple and conflicting criteria (Kumar, 2024). These methods provide a structured framework for objectively evaluating multiple criteria (Sahoo et al., 2024). Unlike traditional MCDM methods, the integration of MCDM methods based on fuzzy logic theory with fuzzy numbers has emerged. Fuzzy logic offers a mathematical approach for representing uncertainty and ambiguity (Çolak and Kaya, 2017). In recent years, various authors have developed different MCDM methods. There are some differences among these methods. These differences include the level of complexity of the algorithms, the type of weighting of the criteria, the representation of preferences, the inclusion of uncertain data, and the types of data collection (Bączkiewicz et al., 2021). In contrast, MCDM methods share some common steps. Wang et al. listed the common steps in various MCDM methods as follows (Wang et al., 2024):

Step 1: The Alternative-Criteria Matrix is created.

Step 2: The criterion values in the created matrix are normalized.

Step 3: Weights are assigned to the criterion values.

Step 4: The alternatives are ranked using one or more MCDM methods.

This study addresses the problem of ranking alternatives. Given their economic and logistical significance, this study focuses on the top 20 airports as ranked by Skytrax for 2025. The study aimed to obtain the performance scores of the top 20 airports determined for 2025. The triangular fuzzy MEREC and ARAS methods are used in the study.

3. 1. TRIANGULAR FUZZY MEREC

Triangular Fuzzy MEREC is a method that combines Triangular Fuzzy Numbers (TFNs) and the Criterion Removal Method (MEREC). The TFMEREC method is a more advanced analytical method based on traditional MEREC. The TFMEREC method is used to determine criterion weights based on the evaluations of a group of decision makers. TFMEREC integrates triangular fuzzy numbers with MEREC, providing more accurate weights under uncertainty where traditional methods such as AHP and TOPSIS fall short (Hasnan et al., 2024). In this study, TFMEREC is used because it increases the accuracy and reliability of determining criterion weights. The triangular linguistic variables in Table 1 are shown for the linguistic variables.

Table 1. Linguistic Variables and Non-Zero TFNs

Statement	Scale
Absolute Low (AL)	(1,1,1)
Very Low (VL)	(1,2,3)
Low (L)	(2,3,4)
Slightly Low (SL)	(3,4,5)
Fair (F)	(4,5,6)
Medium High (MH)	(5,6,7)
High (H)	(6,7,8)
Very High (VH)	(7,8,9)
Absolutely High (AH)	(8,9,9)

Source: Hasnan et al. (2024)

The steps of the TFMEREC method are explained below (Hasnan et al., 2024):

Step 1. Modelling Linguistic Variables with TFN

The assessment of criteria is conducted using linguistic variables, which are then represented using TFNs.

Step 2. Forming the Decision-Making Matrix.

Each element of this matrix is represented by x_{ij} and must take values greater than zero ($x_{ij} > 0$). These values will be used in the calculations in the following stages: the real natural logarithm function ln (x) is defined only for positive values x_{ij}.

Step 3. Forming Normalized Fuzzy Decision Matrix

The decision matrix is normalized with equations (1) and (2). In the normalization step, cost criteria are converted into benefit criteria and vice versa.

Let where $x_{ij} = (a^l_{ij}, a^m_{ij}, a^u_{ij})$ is the value of criterion j in alternative i, min(x) and are the max-(x) minimum and maximum values of x across all options, and n_{ij} are the normalized benefit and cost values, respectively. If B shows the set of beneficial criteria, and C represents the cost criteria, by utilizing the following equation for linear technique normalization when applying it to a triangular fuzzy number (Bellemare and Wichman, 2020):

$$n_{Lij} = \frac{min\, a_{ij}^{l}}{a_{ij}^{u}}, \frac{min\, a_{ij}^{l}}{a_{ij}^{m}}, \frac{min\, a_{ij}^{l}}{a_{ij}^{l}}, j \in B \tag{1}$$

$$n_{Lij} = \frac{a_{ij}^{l}}{max\, c_{ij}^{l}}, \frac{a_{ij}^{m}}{max\, c_{ij}^{m}}, \frac{a_{ij}^{l}}{max\, c_{ij}^{l}}, j \in C \tag{2}$$

Step 4. Calculating The Overall Performance of the Alternatives.

Then, the improved logarithm function developed by Shannon (Zhou et al., 2006) is used to determine the performance of the alternatives (Kullback, 1997; Kullback and Leibler, 1951). The new formula for calculating the overall performance of the alternatives is presented in Equation (3).

$$Q_i = ln\left(1 + \left(\frac{1}{m}\sum_{k, k \neq j} |ln(c_{ik}^{x})|\right)\right), ln\left(1 + \left(\frac{1}{m}\sum_{k, k \neq j} |ln(b_{ik}^{x})|\right)\right), ln\left(1 + \left(\frac{1}{m}\sum_{k, k \neq j} |ln(a_{ik}^{x})|\right)\right) \tag{3}$$

Step 5. Calculating The Performance of Alternatives by Eliminating Each Criterion

The logarithm function is the same as in step 4, but each criterion is removed one by one. This step is calculated using Equation (4).

$$Q_{ij}' = (S_l, S_m, S_r) \tag{4}$$

Step 6. Calculating The Distance of Each Alternative.

The distance is calculated using Equation (5).

$$V_S = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2} \tag{5}$$

Step 7. Calculating The Objective Weights of The Criteria.

The objective weights of the criteria are calculated by Equation (6).

$$W_j = \frac{E_j}{\sum_k E_k} \tag{6}$$

3. 2. ARAS

The Additive Ratio Evaluation (ARAS) method is a multi-criteria decision-making technique that ranks alternatives by comparing the utility levels of each alternative with the most suitable one (Zavadskas and Turskis, 2010). ARAS is a new MCDM method compared to other methods (Goswami et al., 2021). Compared to other decision-making approaches, the ARAS method offers a notable advantage by ensuring more reliable outcomes and minimizing rank reversal, which is a frequent limitation in alternative methods (Turskis and Keršulienė, 2024). In this study, the ARAS method is used because it is both easy and effective in solving MCDM problems. The ARAS method is frequently used in numerous studies to address various decision-making problems.

The steps of the ARAS method are explained below (Zavadskas and Turskis, 2010):

Step 1. Forming a Decision-Making Matrix

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \quad j = \overline{1, n}. \tag{7}$$

This decision matrix shows the scores for the alternatives and criteria related to the decision problem. Unlike other MCDM methods, this matrix includes a row containing the optimal values for the criteria.

The optimal value is calculated using Equations (8) and (9), based on the logic of maximizing benefit and minimizing cost. The optimal values for each column are found with the following equations.

$$x_{0j} = max_i x_{ij}, \text{ if the criterion is benefit;} \tag{8}$$

$$x_{0j} = min_i x_{ij}, \text{ if the criterion is cost;} \tag{9}$$

Step 2. Forming the Normalized Decision-Making Matrix

With Equation (10) and (11), all values in the decision matrix are normalized.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}, \text{ if the criterion is benefit;} \tag{10}$$

$$\bar{x}_{ij} = \frac{1}{x_{ij}}; \ \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}, \text{ if the criterion is benefit;} \tag{11}$$

Step 3.Forming the Normalized Weighted Decision-Making Matrix

The weighted normalized values ($\bar{x}_{ij}$) are found by multiplying the normalized values (w_j) by the criteria weights ($\hat{x}_{ij}$) obtained with the TFMEREC method. The product of the normalized values and the weights is given in Equation (12).

$$\hat{x}_{ij} = \bar{x}_{ij}, w_j; \ i = \overline{0, m}, \tag{12}$$

Step 4. Calculating the Optimality Function Value

The optimality function value is calculated using Equation (13).

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \ i = 1, \ldots m \tag{13}$$

Step 5. Calculating of Utility Degree and The Final Ranking of Alternatives

The utility value () of each alternative is found with Equation (14). The values are ranked from largest to smallest. The best alternative has the largest utility value.

$$K_i = \frac{S_i}{S_0} \tag{14}$$

4. DATASET AND THE APPLICATION

Skytrax publishes a list of the world's top 100 airports annually. In this study, the top 20 airports were considered as an alternative to narrow the scope and increase the depth of analysis. Skytrax evaluates airports under 11 main criteria. These evaluation criteria have also been applied to evaluate and explain airport service quality in academic literature (Lee and Yu, 2017; Bulatovic et al., 2023, Dempere and Papatheodorou, 2023). Each criterion comprises various subcomponents related to the relevant service area, and each subassessment is scored on a scale of 5 stars. In the analyses, the overall score for each criterion is calculated by averaging the sub-assessments for that criterion. To standardize the rating system, the 5-star scale was normalized to a full 100 points (1 star = 20 points, five stars = 100 points). This yields the final average scores for each criterion. The TFMEREC method, a more advanced analytical method based on the traditional MEREC, was used to weight the criteria. In this study, this method was chosen to eliminate uncertainty in the decision-making process. MEREC has been used in numerous studies as a method that provides flexibility in objectively weighting criteria. The decision matrix was obtained from data published in 2025. The decision matrix, created with the final average scores for each criterion, was evaluated using the ARAS method. The criteria and alternative list are in Table 2.

Table 2. Criteria and Alternative List

Criteria	Criteria Description	Alternatives
C1-Ground Transportation	Availability, convenience, and efficiency of public transport, taxis, and car rental access to/from the airport.	SIN-Singapore Changi Airport
C2-Security Screening	Waiting time, efficiency of the process, staff courtesy, and professionalism during security checks.	DOH-Hamad International Airport
C3-Immigration Service	Efficiency and waiting time at immigration, staff attitude, and availability of fast-track options.	HND-Tokyo Haneda Airport
C4-Wayfinding & Signage	Clarity and visibility of signs, ease of navigation in arrivals, transfers, and departures.	ICM-Incheon International Airport
C5-Arrival	Walking distances, baggage claim efficiency, cleanliness, and passenger facilities upon arrival.	NRT-Narita International Airport
C6-Departure	Check-in process, queue organization, signage, and availability of seating in departure areas.	HKG-Hong Kong International Airport
C7-Transfer	Ease and clarity of transfer routes, signage, walking distances, and transfer security procedures.	CDG-Paris Charles de Gaulle Airport
C8-Terminal Comfort	Overall comfort of the terminal includes seating, cleanliness, ambience, and relaxation areas.	FCO-Rome Fiumicino Airport
C9-Terminal Facilities	Range and quality of facilities such as Wi-Fi, ATMs, baby care rooms, rest zones, and vending machines.	MUC-Munich Airport
C10-Shopping Facilities	Variety and quality of retail shops, availability of luxury and mid-range brands, staff service.	ZRH-Zurich Airport
C11-Food & Beverage	Quality, variety, and presentation of food and drink outlets across the airport.	DXB-Dubai International Airport
		HEL-Helsinki-Vantaa Airport
		YVR-Vancouver International Airport
		IST-Istanbul Airport
		VIE-Vienna International Airport
		MEL-Melbourne Airport
		NGO-Chubu Centrair International Airport
		CPH-Copenhagen Airport
		AMS-Amsterdam Schiphol Airport
		BAH-Bahrain International Airport

Source: Skytrax (2025)

The criteria were weighted by the responses of a group of expert decision makers in the airport field. To ensure a balanced integration of theory and practice, two international airline managers and two logistics professors were engaged in the evaluation process. Their expertise represented a balance between industry experience and theoretical knowledge, ensuring objectivity and credibility in the weighting of criteria. The linguistic scales in Table 1 were converted to triangular fuzzy numbers. The next step is to multiply these values by the corresponding weights. In this study, the four experts participating in the evaluation process possess a balanced distribution of expertise. The opinions of both practitioners (airport company managers) and academics who can offer theoretical perspectives contribute equally to the evaluation process. Therefore, to ensure equal representation of each decision-maker's opinion in the study, the weightings were set at 0.25. This aims to ensure objectivity in the decision-making process by preventing any one decision-maker's opinion from being overshadowed by others. The weighted decision matrices, which contain the opinions of four decision makers, are presented below. As an illustration,

$$(SIN, C1) = (7 \times 0.25, 8 \times 0.25, 9 \times 0.25) = (1.75, 2, 2.25) \tag{15}$$

Table 3. Weighted Decision Matrix DM1

	C1	C2	…	C10	C11
SIN	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)	…	(1.75, 2.00, 2.25)	(2.00, 2.25, 2.25)
DOH	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)	…	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)
	…	…	…	…	…
AMS	(1.25, 1.50, 1.75)	(1.00, 1.25, 1.50)	…	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)
BAH	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)	…	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)

Source: Author`s calculation

Table 4. Weighted Decision Matrix DM2

	C1	C2	…	C10	C11
SIN	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)	…	(1.75, 2.00, 2.25)	(2.00, 2.25, 2.25)
DOH	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)	…	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)
	…	…	…	…	…
AMS	(1.25, 1.50, 1.75)	(1.00, 1.25, 1.50)	…	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)
BAH	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)	…	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)

Source: Author`s calculation

Table 5. Weighted Decision Matrix DM3

	C1	C2	…	C10	C11
SIN	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)	…	(1.75, 2.00, 2.25)	(2.00, 2.25, 2.25)
DOH	(2.00, 2.25, 2.25)	(1.25, 1.50, 1.75)	…	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)
	…	…	…	…	…
AMS	(1.25, 1.50, 1.75)	(1.00, 1.25, 1.50)	…	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)
BAH	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)	…	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)

Source: Author`s calculation

Table 6. Weighted Decision Matrix DM4

	C1	C2	…	C10	C11
SIN	(2.00, 2.25, 2.25)	(1.50, 1.75, 2.00)	…	(1.75, 2.00, 2.25)	(2.00, 2.25, 2.25)
DOH	(1.75, 2.00, 2.25)	(1.25, 1.50, 1.75)	…	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)
	…	…	…	…	…
AMS	(1.25, 1.50, 1.75)	(1.00, 1.25, 1.50)	…	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)
BAH	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)	…	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)

Source: Author`s calculation

The decision makers' responses were compiled into a single response decision matrix after the following defuzzification calculations.

$$(SIN_{11}^{l}, SIN_{11}^{m}, SIN_{11}^{u}) = \left(min\,(SIN_{11}^{l}), \frac{\sum SIN_{11}^{m}}{4}, max\,(SIN_{11}^{u})\right)$$
$$= \left(min\,(1.75, 1.75, 1.75, 2.00), \frac{(2.00, 2.00, 2.00\ 2.25)}{4}, max\,(2.25, 2.25, 2.25, 2.25)\right)$$

Table 7. The Weighted Defuzzification Decision Matrix

	C1	C2	…	C10	C11
SIN	(1.75, 2.06, 2.25)	(1.50, 1.75, 2.00)	…	(1.75, 2.00, 2.25)	(2.00, 2.25, 2.25)
DOH	(1.75, 2.18, 2.25)	(1.25, 1.87, 2.25)	…	(2.00, 2.25, 2.25)	(2.00, 2.25, 2.25)
	…	…	…	…	…
AMS	(1.25, 1.50, 1.75)	(1.00, 1.25, 1.50)	…	(1.75, 2.00, 2.25)	(1.50, 1.75, 2.00)
BAH	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)	…	(1.25, 1.50, 1.75)	(1.25, 1.50, 1.75)

Source: Author`s calculation

Linear normalization in terms of benefit and cost criteria is calculated by Equations (1) and (2).

Table 8. The Weighted Normalized Fuzzy Decision Matrix

	C1	C2	…	C10	C11
SIN	(0.55, 0.60, 0.71)	(0.50, 0.57, 0.66)	…	(0.55, 0.62, 0.71)	(0.55, 0.55, 0.62)
DOH	(0.55, 0.57, 0.71)	(0.44, 0.53, 0.80)	…	(0.55, 0.55, 0.62)	(0.55, 0.55, 0.62)
	…	…	…	…	…
AMS	(0.71, 0.83, 1.00)	(0.66, 0.80, 1.00)	…	(0.55, 0.62, 0.71)	(0.62, 0.71, 0.83)
BAH	(0.71, 0.83, 1.00)	(0.57, 0.66, 0.80)	…	(0.71, 0.83, 1.00)	(0.71, 0.83, 1.00)

Source: Author`s calculation

The overall effectiveness of the alternatives is then calculated using Equation (3).

Table 9. The Overall Effectiveness of the Alternatives (Q)

SIN	(0.38, 0.48, 0.51)
DOH	(0.38, 0.50, 0.51)
HND	(0.29, 0.40, 0.49)
ICM	(0.39, 0.48, 0.51)
NRT	(0.15, 0.30, 0.40)
HKG	(0.32, 0.43, 0.51)
CDG	(0.04, 0.21, 0.32)
FCO	(0.07, 0.23, 0.35)
MUC	(0.21, 0.36, 0.45)
ZRH	(0.30, 0.42, 0.51)
DXB	(0.20, 0.61, 0.46)
HEL	(0.24, 0.38, 0.47)
YVR	(0.12, 0.28, 0.39)
IST	(0.10, 0.31, 0.41)
VIE	(0.13, 0.32, 0.43)
MEL	(0.06, 0.25, 0.37)
NGO	(0.19, 0.34, 0.44)
CPH	(0.29, 0.41, 0.50)
AMS	(0.05, 0.25, 0.38)
BAH	(0.08, 0.23, 0.35)

Source: Author`s calculation

The performance of the alternatives (Q') is calculated using Equation (4).

Table 10. The Performance of the Alternatives (Q')

	C1	C2	…	C10	C11
SIN	(0.36, 0.44, 0.47)	(0.35, 0.44, 0.46)	…	(0.36, 0.44, 0.47)	(0.35, 0.44, 0.47)
DOH	(0.35, 0.46, 0.47)	(0.36, 0.45, 0.46)	…	(0.34, 0.46, 0.47)	(0.34, 0.46, 0.47)
	…	…	…	…	…
AMS	(0.04, 0.23, 0.35)	(0.04, 0.23, 0.35)	…	(0.01, 0.21, 0.34)	(0.03, 0.22, 0.34)
BAH	(0.07, 0.22, 0.32)	(0.05, 0.20, 0.31)	…	(0.07, 0.22, 0.32)	(0.07, 0.22, 0.32)

Source: Author`s calculation

The separation distance of the alternatives is calculated using Equation (5).

Table 11. Separation Distance

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
SIN	0,05	0,06	0,07	0,06	0,06	0,08	0,08	0,05	0,05	0,05	0,06
DOH	0,05	0,06	0,07	0,06	0,06	0,08	0,08	0,05	0,05	0,06	0,06
HND	0,05	0,06	0,06	0,05	0,05	0,07	0,06	0,04	0,04	0,05	0,04
ICM	0,05	0,07	0,07	0,06	0,06	0,08	0,08	0,05	0,05	0,05	0,06
NRT	0,04	0,05	0,05	0,04	0,04	0,07	0,05	0,04	0,02	0,04	0,02
HKG	0,05	0,05	0,07	0,05	0,05	0,07	0,07	0,04	0,04	0,05	0,06
CDG	0,03	0,02	0,03	0,03	0,03	0,05	0,03	0,03	0,03	0,05	0,03
FCO	0,04	0,05	0,03	0,03	0,03	0,05	0,03	0,03	0,03	0,03	0,04
MUC	0,04	0,06	0,06	0,04	0,04	0,08	0,06	0,03	0,03	0,04	0,04
ZRH	0,05	0,07	0,07	0,05	0,05	0,07	0,06	0,04	0,04	0,04	0,05
DXB	0,04	0,06	0,03	0,03	0,03	0,07	0,04	0,04	0,03	0,30	0,05
HEL	0,04	0,05	0,06	0,05	0,05	0,06	0,06	0,05	0,05	0,05	0,04
YVR	0,03	0,05	0,03	0,02	0,04	0,07	0,05	0,02	0,04	0,04	0,04
IST	0,02	0,06	0,04	0,05	0,03	0,07	0,05	0,03	0,02	0,05	0,04
VIE	0,04	0,06	0,04	0,03	0,04	0,07	0,07	0,03	0,03	0,04	0,04
MEL	0,02	0,06	0,05	0,04	0,02	0,05	0,05	0,02	0,02	0,02	0,02
NGO	0,03	0,06	0,06	0,04	0,04	0,06	0,06	0,03	0,03	0,04	0,04
CPH	0,05	0,07	0,05	0,05	0,05	0,07	0,07	0,04	0,04	0,04	0,05
AMS	0,02	0,03	0,03	0,02	0,04	0,06	0,04	0,02	0,04	0,06	0,04
BAH	0,03	0,05	0,05	0,03	0,03	0,05	0,05	0,03	0,03	0,03	0,03
SUM	10,39										

Source: Author`s calculation

Finally, the weights of the criteria are calculated with Equation (6).

Table 12. The Weight of The Criteria

C#	Criteria	W	%
C1	Ground Transportation	0,77	7%
C2	Security Screening	1,10	11%
C3	Immigration Service	1,04	10%
C4	Wayfinding & Signage	0,81	8%
C5	Arrival	0,81	8%
C6	Departure	1,33	13%
C7	Transfer	1,14	11%
C8	Terminal Comfort	0,74	7%
C9	Terminal Facilities	0,73	7%
C10	Shopping Facilities	1,11	11%
C11	Food & Beverage	0,82	8%

Source: Author`s calculation

According to the findings, “Departure” emerges as the most important criterion, with a weight of 13%. This is followed by “Security Screening,” “Transfer,” and “Shopping Facilities” with equal weights of 11%, and “Immigration Service” with 10%. These results indicate that efficient departure processes, passenger security, transfer operations, and shopping opportunities play a decisive role in airport satisfaction. On the other hand, “Wayfinding & Signage,” “Arrival,” and “Food & Beverage” (each 8%) have a medium level of importance. Finally, “Ground Transportation,” “Terminal Comfort,” and “Terminal Facilities” (each 7%) are among the relatively less important criteria in the evaluation. Overall, these results suggest that while operational efficiency and service quality remain important, passengers place a strong emphasis on both security and the overall travel experience.

Table 13. Initial Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	0,07	0,11	0,10	0,08	0,08	0,13	0,11	0,07	0,07	0,11	0,08
Optimal	93,33	94,53	96	96,42	95,83	96,67	95	94,6	96,1	96	94,44
SIN	91,25	86,6	85	94,2	95,41	96,25	86,93	92,43	96,1	92	90,28
DOH	82,5	83,33	82	88,33	90	95	86,6	90	93,33	92	91,11
HND	93,33	86,66	64	94,72	91,66	87,22	94	91,51	86,4	87,33	83,33
ICN	86,25	80,83	83	95,42	95,83	96,67	95	93,63	92,08	89,2	88,3
NRT	87,5	94,53	85,16	96,42	95,55	89,55	91,5	93,6	92,66	90,66	88,14
HKG	90	80	92	90	95	83,33	86,6	90	88,4	96	94,44
CDG	84,16	78,88	78	82,25	81,11	80,33	79,42	78,18	83,56	79,33	80,69
FCO	92,5	88,2	90	93,6	90	85	92,5	91,8	90	94	84,44
MUC	88,75	83,66	81,25	94,5	85,83	92,83	84,16	89,96	90,33	88	91,58
ZRH	85	86,6	80	75,4	81,67	78,33	80	81,8	76,67	90	82,22
DXB	77,5	63,33	66	71,82	71,67	65	72,5	64,55	77,5	78	72,22
HEL	82,5	81,67	78	80	73,33	71,67	80	78	81,8	78	78,89
YVR	72,5	78,33	75	79	83,33	65	74	75,4	83	70	77,78
IST	85	86,6	80	86	25	86,6	78,33	81	72,6	86	82,22
VIE	81,25	72,5	65	72,5	79,19	67,5	70	81,86	76,86	79	78,33
MEL	67,5	78,33	75	72	68,33	66,67	80	68	71	70	63,33
NGO	92,5	89	88,75	87,72	85	89	92,5	92,22	89,27	82	86,66
CPH	82,5	81,67	77,5	81	80	76	77,5	79	81	82	80
AMS	90	81,67	82,5	81	80	80	80	80,8	83,8	84	82,22
BAH	87,5	93,33	96	92,6	93,33	95	91,6	94,6	90	84	94,4

Source: Author`s calculation

Table 14. Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	0,07	0,11	0,10	0,08	0,08	0,13	0,11	0,07	0,07	0,11	0,08
Optimal	0,052	0,054	0,056	0,053	0,055	0,055	0,054	0,053	0,054	0,054	0,054
SIN	0,051	0,049	0,050	0,052	0,055	0,055	0,049	0,052	0,054	0,051	0,051
DOH	0,046	0,048	0,048	0,049	0,052	0,054	0,049	0,050	0,052	0,051	0,052
HND	0,052	0,050	0,038	0,052	0,053	0,050	0,053	0,051	0,048	0,049	0,047
ICN	0,048	0,046	0,049	0,053	0,055	0,055	0,054	0,053	0,051	0,050	0,050
NRT	0,049	0,054	0,050	0,053	0,055	0,051	0,052	0,052	0,052	0,051	0,050
HKG	0,050	0,046	0,054	0,050	0,055	0,048	0,049	0,050	0,049	0,054	0,054
CDG	0,047	0,045	0,046	0,046	0,047	0,046	0,045	0,044	0,047	0,044	0,046
FCO	0,052	0,050	0,053	0,052	0,052	0,049	0,052	0,051	0,050	0,053	0,048
MUC	0,049	0,048	0,048	0,052	0,049	0,053	0,048	0,050	0,050	0,049	0,052
ZRH	0,047	0,049	0,047	0,042	0,047	0,045	0,045	0,046	0,043	0,050	0,047
DXB	0,043	0,036	0,039	0,040	0,041	0,037	0,041	0,036	0,043	0,044	0,041

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
HEL	0,046	0,047	0,046	0,044	0,042	0,041	0,045	0,044	0,046	0,044	0,045
YVR	0,040	0,045	0,044	0,044	0,048	0,037	0,042	0,042	0,046	0,039	0,044
IST	0,047	0,049	0,047	0,048	0,014	0,050	0,044	0,045	0,041	0,048	0,047
VIE	0,045	0,041	0,038	0,040	0,046	0,039	0,040	0,046	0,043	0,044	0,044
MEL	0,038	0,045	0,044	0,040	0,039	0,038	0,045	0,038	0,040	0,039	0,036
NGO	0,052	0,051	0,052	0,049	0,049	0,051	0,052	0,052	0,050	0,046	0,049
CPH	0,046	0,047	0,046	0,045	0,046	0,044	0,044	0,044	0,045	0,046	0,045
AMS	0,050	0,047	0,049	0,045	0,046	0,046	0,045	0,045	0,047	0,047	0,047
BAH	0,049	0,053	0,056	0,051	0,054	0,054	0,052	0,053	0,050	0,047	0,053

Source: Author`s calculation

Table 15. Weighted Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	0,07	0,11	0,1	0,08	0,08	0,13	0,11	0,07	0,07	0,11	0,08
Optimal	0,004	0,006	0,006	0,004	0,004	0,007	0,006	0,004	0,004	0,006	0,004
SIN	0,004	0,005	0,005	0,004	0,004	0,007	0,005	0,004	0,004	0,006	0,004
DOH	0,003	0,005	0,005	0,004	0,004	0,007	0,005	0,004	0,004	0,006	0,004
HND	0,004	0,005	0,004	0,004	0,004	0,007	0,006	0,004	0,003	0,005	0,004
ICM	0,003	0,005	0,005	0,004	0,004	0,007	0,006	0,004	0,004	0,005	0,004
NRT	0,003	0,006	0,005	0,004	0,004	0,007	0,006	0,004	0,004	0,006	0,004
HKG	0,004	0,005	0,005	0,004	0,004	0,006	0,005	0,004	0,003	0,006	0,004
CDG	0,003	0,005	0,005	0,004	0,004	0,006	0,005	0,003	0,003	0,005	0,004
FCO	0,004	0,006	0,005	0,004	0,004	0,006	0,006	0,004	0,004	0,006	0,004
MUC	0,003	0,005	0,005	0,004	0,004	0,007	0,005	0,004	0,004	0,005	0,004
ZRH	0,003	0,005	0,005	0,003	0,004	0,006	0,005	0,003	0,003	0,006	0,004
DXB	0,003	0,004	0,004	0,003	0,003	0,005	0,005	0,003	0,003	0,005	0,003
HEL	0,003	0,005	0,005	0,004	0,003	0,005	0,005	0,003	0,003	0,005	0,004
YVR	0,003	0,005	0,004	0,004	0,004	0,005	0,005	0,003	0,003	0,004	0,004
IST	0,003	0,005	0,005	0,004	0,001	0,006	0,005	0,003	0,003	0,005	0,004
VIE	0,003	0,005	0,004	0,003	0,004	0,005	0,004	0,003	0,003	0,005	0,004
MEL	0,003	0,005	0,004	0,003	0,003	0,005	0,005	0,003	0,003	0,004	0,003
NGO	0,004	0,006	0,005	0,004	0,004	0,007	0,006	0,004	0,003	0,005	0,004
CPH	0,003	0,005	0,005	0,004	0,004	0,006	0,005	0,003	0,003	0,005	0,004
AMS	0,004	0,005	0,005	0,004	0,004	0,006	0,005	0,003	0,003	0,005	0,004
BAH	0,003	0,006	0,006	0,004	0,004	0,007	0,006	0,004	0,004	0,005	0,004

Source: Author`s calculation

Table 16. Si, Ki Values and The Ranking of Alternatives

Alternatives	Si	Ki	Ranking
Optimal	0,055		
SIN	0,052	0,956	2
DOH	0,051	0,929	7
HND	0,050	0,910	10
ICM	0,052	0,948	4
NRT	0,052	0,956	3
HKG	0,051	0,934	6
CDG	0,046	0,841	13
FCO	0,052	0,943	5
MUC	0,050	0,922	9
ZRH	0,047	0,857	12

Alternatives	Si	Ki	Ranking
DXB	0,040	0,738	20
HEL	0,045	0,819	15
YVR	0,043	0,786	17
IST	0,045	0,819	16
VIE	0,042	0,776	18
MEL	0,041	0,747	19
NGO	0,051	0,927	8
CPH	0,046	0,834	14
AMS	0,047	0,860	11
BAH	0,053	0,965	1

Source: Author`s calculation

5. DISCUSSION

Scientifically based airport assessments provide practitioners and academics with valuable information. Multi-criteria decision-making methods allow airports to be analysed from various angles. These methods facilitate more informed decisions regarding the efficient use of resources, infrastructure investment, and operational strategy. Standardized comparisons enhance global competition and promote sustainability, environmental performance, and technological advancement. Such studies offer practical solutions and inform academic research, making valuable contributions to the literature.

This study evaluated 20 international airports based on 11 service criteria. Bahrain International Airport (BAH) achieved the highest performance ranking, while Dubai International Airport (DBX) achieved the lowest. The analysis considered multifaceted factors, including departure processes, transfer services, security screening, shopping facilities, and immigration service, revealing the airports' strengths and areas for improvement. Such comparative analyses can significantly increase operational efficiency and improve passenger satisfaction. They also pave the way for raising quality standards across the sector.

Airport operators at the bottom of the ranking should develop policies to improve service quality and increase passenger satisfaction. This could involve introducing digital solutions and automation systems, particularly in critical areas such as departure processes, transfer services, and security screening. Passenger experience could be enhanced by improving immigration procedures as well as the quality of shopping, food, and beverage facilities. Enhancing terminal comfort and providing clear, multilingual directional signage would also contribute to overall satisfaction. Performance-based evaluations are crucial for driving continuous improvement and ensuring alignment with international standards. Implementing these approaches will make airports more competitive and enhance their global standing.

5. 1. THEORETICAL CONTRIBUTION OF THE RESEARCH TO THE LITERATURE

The literature review in this study contributes to the existing literature by focusing on multidimensional areas such as airport management, digitalization and customer experience. The existing literature contains numerous studies on airports. However, multidimensional airport analyses conducted using the criteria, methods, and data used in this study are quite rare. In this context, the prominence of Bahrain Airport confirms its strategic role in existing literature (Schultz et al., 2021). This study focuses on Bahrain and Narita airports (etc.), which are both notable for their strategic locations within regional and global air transport networks. Bahrain International Airport plays a key role in facilitating transit traffic between Asia and Europe. This airport provides highly efficient services for passengers and cargo. Similarly, Narita International Airport is a major global hub for Japan's long-haul international flights. Although located some distance from the city center, this airport has largely overcome accessibility issues thanks to its rail links. Both airports perform well in terms of infrastructure, connectivity, and traffic management, enabling them to compete both nationally and globally. These findings suggest that airports should be evaluated based on their physical capacity and functionality within the network.

The literature demonstrates that airport performance is closely linked to digital services that enhance operational efficiency and passenger experience. In the context of service quality at Changi Airport, the effectiveness of self-service check-in systems has been re-evaluated, as seen by Lee et al. (Lee et al., 2014). Wu and Tsui, emphasize that the "Changi Rewards" application can increase customer loyalty and generate additional revenue (Wu and Tsui, 2020).

Literature also emphasises the growing importance of non-aviation revenue sources and experience-based strategies in airport management. Additionally, Chutiphongdech and Phengkona show that the use of events as a marketing tool transforms airports into multifunctional spaces (Chutiphongdech and Phengkona, 2024). This calls for a reconsideration of the role of airports in tourism and urban economics literature.

The 100% contactless service applications and digitalisation process proposed by Kim et al. (Kim et al., 2025) are grounded in the existing body of literature on the technological transformation of services. In the post-COVID-19 period, contactless transactions have gained even more importance with the smart airport approach in terms of digital service and user experience.

According to the literature, low-performing airports need to improve service quality and operational efficiency through digital investments. Contactless transaction systems, self-service check-in kiosks, and digital guidance tools can reduce costs and boost passenger satisfaction. Airports should also be designed as social and commercial spaces, offering events, shops, and recreational areas to enhance passenger experience. Improving these areas also contributes to financial sustainability by increasing non-aviation revenues. It is also crucial to enhance the airport's regional appeal through effective marketing and branding strategies to boost tourism and attract transit passengers. Ultimately, holistic transformation, supported by environmentally sound practices and sustainability goals, will make these airports more competitive.

5. 2. POLICY RECOMMENDATIONS

Policymakers can enhance the sector's quality and competitiveness by developing supportive policies that promote efficient airport operations. To this end, they should establish financial support programs to encourage investment in infrastructure and provide grants for airport projects related to digitalization, automation, and sustainability. Furthermore, national framework policies should be developed to set service standards and ensure a minimum level of quality at all airports. Personnel quality should be increased through training and data-driven management systems should be encouraged. Supporting international cooperation and information sharing could enhance the global competitiveness of local airports.

5. 3. RESEARCH RECOMMENDATIONS

Future research could contribute to existing literature by adopting a more in-depth and dynamic approach to evaluating airport performance. Firstly, the impact of passenger profile, travel purpose, and demographic characteristics on service satisfaction requires further research. Secondly, multi-criteria evaluation models should incorporate sustainability, environmental impact, and carbon footprint to assess environmental performance. Utilizing real-time data and artificial intelligence-supported analysis methods can enhance the accuracy of decision support systems. Comparative studies of airports in different regions can present new areas of research by revealing cultural and operational differences. Such studies would provide strategic insights for both practitioners and academics.

5. 4. LIMITATIONS OF THE STUDY AND FUTURE RESEARCH

One of the main limitations of this study is that it was conducted in only 20 airports. This small sample size means that the findings cannot be generalised. Furthermore, the airports were evaluated using only 11 criteria. This restricted the scope of the research, meaning that the results obtained were confined to this framework.

From a methodological perspective, it is noteworthy that the study adopted a relatively new approach in MCDM literature. However, as the method is new, direct comparisons with previous studies are difficult to make. While this restricts comparisons with existing literature, it also adds to the originality of the research.

Nevertheless, this study could be replicated using different datasets. Such replication could help to test the robustness of the findings and produce more reliable results. Similarly, approaching the problem from alternative perspectives by defining and incorporating different criteria into the evaluation process would be possible. This kind of methodological diversity would broaden the scope of the research, enabling the results to be considered from a more holistic perspective.

6. CONCLUSION

Airports are a critical element in sustainable transportation networks. While they facilitate the movement of people, goods, and services, they have also become indicators of economic growth (Melgar et al., 2024; Zhang et al., 2010). Combined with their strategic location and passenger and cargo management, these terminals have become indispensable on a global scale. This importance is particularly evident at global airports, where international traffic is concentrated. In the past, airports were primarily terminals providing air transportation services. In today's modern world, they are considered strategic service centers that impact passenger satisfaction, create added economic value, and offer a competitive advantage. In this context, multidimensional evaluation of airport performance is critical for informed decisions in areas such as infrastructure, service quality and passenger experience (Lu et al., 2018; Bezerra and Gomes, 2016; Cohen and Morrison Paul, 2003). This study presents a novel hybrid MCDM framework for evaluating the performance of global airports. The top 20 airports in Skytrax's 2025 rankings, evaluated using 11 criteria, were analyzed. Criteria weights were determined using the TFMEREC method. No studies on TFMEREC performance measurement were found in the existing literature. This makes the study valuable and distinct from others.

The analysis results indicate that Departure processes, Transfer services, and Security Screening are the most important criteria. These findings demonstrate that airport performance is determined not only by operational efficiency but also by the quality of passenger-focused services. The ranking of the alternatives was conducted using the ARAS method. Bahrain International Airport was identified as the highest-performing airport in the ranking, followed by Singapore Changi Airport and Narita International Airport. Narita Airport's location in the Asia-Pacific region, its comprehensive service structure, and its international connections are the key factors supporting its high performance. This study is the first follow-up study in the literature following the method's original introduction and initial application. This demonstrates the objective and systematic approach that the newly developed method provides in decision-making processes. Future studies could conduct differentiated analyses using other multi-criteria decision-making methods such as TOPSIS, COPRAS, and CODAS. The development of hybrid models supported by qualitative data is recommended to strengthen the managerial implications of analytical findings.

Furthermore, the effects of passenger profile, travel purpose, and demographic characteristics on service satisfaction could be examined in more detail in future studies. The use of real-time data and AI-supported analysis techniques has the potential to increase the accuracy of decision support systems. In this context, this study offers both methodological and practical contributions, shedding light on data-driven decision-making processes in airport management.

In summary, this study reveals that airports should be evaluated based on a range of performance criteria related to passenger experience rather than operational efficiency alone. Analysis of the 2025 Skytrax data shows that areas that directly impact passengers, such as departure processes, transfer services, and security screening, have the greatest influence. The new TFMEREC model is a methodological innovation that provides a systematic, objective and comparable assessment process. Bahrain International Airport's top ranking demonstrates the decisive role of passenger service quality in achieving global competitiveness. Furthermore, airports in the Asia-Pacific region are notable for their robust infrastructure and efficient service delivery.

The findings suggest that airport managers and policymakers should prioritise improving essential services such as departure processes, transfer services, and security screening to enhance passenger satisfaction. Tailoring services to different passenger profiles, travel purposes and demographic characteristics would also increase satisfaction levels. The systematic use of multi-criteria decision-making methods, such as TFMEREC, enables more effective management of resources in decision-making processes. Furthermore, monitoring real-time data and utilising artificial intelligence-supported analytics improves the accuracy of decision support systems and strengthens governance capacity. Future investments should prioritise developing both physical and data-driven digital infrastructure.

In summary, this study:

- Novelty of findings: This study is the first to apply the recently introduced HYBRID TFMEREC–ARAS method to evaluate airport performance. It is also the first follow-up study conducted after the method's initial application. Furthermore, it makes a unique contribution to the literature by demonstrating that airport performance is determined not only by operational efficiency, but also by the quality of passenger-focused services. In this regard, the study is innovative in both methodological and content terms.
- Generalisability: The research findings are reliable, particularly within the selected sample of international airports (e.g. Bahrain, Singapore Changi and Narita). However, it may be difficult to generalise these findings directly to all airports or to different regional contexts. Nevertheless, conducting similar studies on airports in different regions could strengthen the validity and generalisability of the results.
- Practical and managerial implications: The research findings have important implications for airport managers and policymakers. In particular, departure processes, transfer services, and security screening play a critical role in the passenger experience. Improving these services could enhance airport competitiveness. From a managerial perspective, the study demonstrates that airport performance should be evaluated not only by operational processes but also by the services that directly impact passenger satisfaction. This encourages managers to adopt a more balanced, passenger-centric approach when determining investment priorities.

In conclusion, this study aims to provide managers and policymakers with a roadmap highlighting the key criteria to consider when making decisions. The identification of departure processes, transfer services, and security screening as priority elements suggests that these services should be prioritised in terms of resource allocation and strategic planning. Airports are also ranked from best to worst based on these criteria. The recommendations are therefore supported by empirical findings and point to specific areas for improvement.

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Ethical Approval

This research does not require any ethics committee permission as it uses open source secondary data.

Author Contributions

Author 1: Research concept and design, data collection, analysis and interpretation, manuscript writing and revision. Author 2: Research concept, introduction and literature review and discussion draft.

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