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Developing a strategic framework for airline destination selection: A multi-criteria decision-making approach applied to Turkish airlines

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ABSTRACT

The purpose of this study is to develop a comprehensive decision-making framework that airlines can use to strategically select new destinations, demonstrated here with a case application for Turkish Airlines. Addressing the complexities of route expansion, the study integrates the Entropy weighting method with the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM) to evaluate potential destinations across critical criteria, including market demand, economic impact, and regulatory environment. Data were collected from industry reports, expert evaluations, and publicly available aviation metrics to support a thorough and adaptable analysis. Findings from the Turkish Airlines case reveal San Antonio, TX (SAT), Portland, OR (PDX), and Nashville, TN (BNA) as top-ranked destinations, each offering distinct economic and operational benefits. This study contributes to aviation management literature by presenting a versatile, data-driven framework that can guide route selection for carriers in competitive markets. The framework's ability to balance quantitative and qualitative insights underscores its potential for broader application in network planning, promoting sustainable growth within the aviation industry.

1. Introduction

The global aviation industry faces constant pressure to optimize route planning and expand networks to meet evolving passenger demands, economic shifts, and competitive pressures. Strategic destination selection is pivotal to airline growth and profitability, shaping market reach, operational efficiency, and long-term competitive positioning. For a global carrier like Turkish Airlines (THY), with one of the largest route networks spanning over 315 destinations across 126 countries, selecting new destinations involves a complex, multi-dimensional decision-making process. This process must account for diverse factors, including market demand, economic viability, operational feasibility, regulatory compliance, and environmental considerations. To address these challenges, THY requires a sophisticated, data-driven framework capable of navigating the uncertainties and complexities inherent in route planning (Turkish Airlines Investor Relations, 2023).

This study is motivated by the need to develop such a framework, enabling the aviation industry to identify and evaluate potential new routes systematically and robustly. The dynamic nature of the industry—marked by rapidly changing passenger preferences, fluctuating economic conditions, and heightened regulatory scrutiny—necessitates decision-making tools that can adapt effectively. For example, the COVID-19 pandemic underscored the need for airlines to realign their route networks swiftly to meet shifting market demands. This research aims to provide a flexible and comprehensive framework that integrates quantitative and qualitative insights, ensuring sustainable growth and competitive advantage.

This study introduces an innovative decision-making model that

Abbreviations: ACI, Airports Council International; AHP, Analytic Hierarchy Process; A4A, Airlines for America; BASA, Bilateral Air Service Agreements; CAPA, Centre for Aviation; CNN, Convolutional Neural Network; FAA, Federal Aviation Administration; GBTA, Global Business Travel Association; ICAO, International Civil Aviation Organization; IATA, International Air Transport Association; IMF, International Monetary Fund; MCDM, Multi-Criteria Decision-Making; OECD, Organisation for Economic Co-operation and Development; PDX, Portland International Airport; SAT, San Antonio International Airport; BNA, Nashville International Airport; TFWA, T-Spherical Fuzzy Weighted Averaging; 2TLTS-FDOSM, 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method; TOPSIS, Technique for Order Preference by Similarity to Ideal Solution; VIKOR, VlseKriterijumska Optimizacija I Kompromisno Resenje (Multi-Criteria Optimization and Compromise Solution); WTTC, World Travel & Tourism Council; WP Travel, World Tourism and Travel Platform.

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integrates the Entropy weighting method with the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM) to address the complexities inherent in strategic destination selection. This combined approach offers a structured framework for evaluating critical criteria while effectively managing uncertainties through advanced fuzzy logic. Central to this framework are several fuzzy set theories that enhance the modeling of uncertainty. Spherical Fuzzy Sets (SFS) extend traditional fuzzy sets by introducing positive, neutral, and negative membership functions under a spherical constraint, providing a balanced representation of uncertainty (Gündoğdu & Kahraman, 2019). T-Spherical Fuzzy Sets (T-SFS) incorporate a parameter ttthat adjusts the flexibility of the membership functions, enabling nuanced modeling of varying levels of uncertainty (Mahmood et al., 2019). Building upon these, 2-Tuple Linguistic T-Spherical Fuzzy Sets (2TLT-SFS) combine T-SFS with linguistic variables, allowing decision-makers to express evaluations using natural language, thereby enhancing interpretability and precision (Dong & Herrera-Viedma, 2014; Akram et al., 2023). This approach effectively manages linguistic uncertainty and ensures computational accuracy, making it a robust tool for decision-making in complex environments.

By integrating these fuzzy frameworks, the proposed model addresses the limitations of traditional Multi-Criteria Decision-Making (MCDM) approaches—such as AHP, TOPSIS, and VIKOR—which often struggle to handle ambiguities in expert evaluations. The Entropy method objectively assigns weights to criteria based on data variability, while the 2TLTS-FDOSM translates expert judgments into measurable scores, offering a balanced, consensus-driven evaluation process.

Existing research highlights the underutilization of these advanced fuzzy frameworks in aviation, despite their proven effectiveness in other sectors (Alamoodi et al., 2024). While previous studies often focus on isolated factors such as operational costs or passenger demand, they fail to address the interdependencies necessary for holistic destination selection. This study fills this gap by combining entropy-based weighting with fuzzy decision-making methods to balance quantitative metrics and qualitative assessments in a unified, adaptable framework. The proposed methodology, applied to Turkish Airlines (THY), demonstrates how airlines can strategically evaluate and prioritize destinations to achieve sustainable growth. By incorporating expert input and managing uncertainty, the model provides actionable insights that balance operational constraints with regulatory and environmental considerations. This research not only advances decision-making practices in aviation management but also expands the application of fuzzy logic to new and complex decision-making contexts.

2. Literature review

2.1. Destination selection

Choosing new destinations for aviation is a complex, multi-faceted task that demands evaluating numerous criteria. Different Multi-Criteria Decision-Making (MCDM) methods have been applied in recent years to tackle this challenge, generating diverse insights and methodologies. For example, Yirgu and Kim (2024) analyzed airport selection and its catchment areas in the US Midwest, exploring factors such as demographic characteristics, economic activity, and transportation infrastructure through spatial analysis and regression models. The study found that regional economic and demographic features play a significant role in airport selection, emphasizing the need for a regional approach in evaluating destination choices. Similarly, Cordera et al. (2024) used a random parameter logit model to analyze airport choice in multi-airport regions, highlighting determinants like trip duration, travel cost, and service adequacy. This research underscores the importance of passenger behavior studies in airport choice, especially in regions where travelers have multiple airport options.

Further refining MCDM applications, Badi et al. (2023) proposed a Grey-CODAS (COmbinative Distance-based Assessment) approach to select a hub airport in North Africa, focusing on factors such as location, economic strengths, and infrastructure quality. This study demonstrates the potential of the Grey-CODAS method in handling ambiguity and uncertainty within airport selection strategies. Meanwhile, Bakır et al. (2021) used fuzzy PIPRECIA and fuzzy MARCOS methods to determine regional aircraft selection in Turkey's airline industry, incorporating operational effectiveness and cost efficiency into their model. This highlights the increasing role of fuzzy MCDM frameworks in addressing the complexity and vagueness inherent in aviation-related decisions.

Špák and Olexa (2020) contributed by enhancing the diversion airport selection methodology, which incorporates factors like infrastructure, weather conditions, and accessibility in emergencies. Their holistic approach surpasses conventional frameworks by the FAA, emphasizing the value of operational and safety factors in airport selection. Along similar lines, Chen et al. (2024) introduced an entropy-weighted fuzzy recognition model with 1D-CNN deep learning to assess general aviation fleet reliability, illustrating the effectiveness of entropy-based methods in supporting reliable fleet operations.

Additionally, Zaid et al. (2024) demonstrated the use of a fuzzy analytic hierarchy process (AHP) for freight transport decision-making from a top management perspective in Bahrain. This study highlights the applicability of fuzzy MCDM approaches in transportation, addressing complex criteria through managerial insights, which can parallel the needs in aviation management.

Moreover, the integration of sustainability into destination planning has gained momentum. Rosenow et al. (2022) developed a next-generation air routing model that combines AI, multi-objective optimization, and collaborative decision-making to achieve efficient and sustainable flight planning, while Hammad et al. (2020) reviewed mathematical optimization techniques to enhance aircraft trajectory sustainability. These studies showcase the aviation industry's growing commitment to environmental considerations in route planning and reinforce the need for MCDM models that incorporate sustainability criteria alongside economic and operational factors.

Recent advancements in fuzzy set theory, including applications of T-spherical fuzzy sets, have significantly expanded the capabilities of Multi-Criteria Decision-Making (MCDM) by enhancing precision and adaptability in complex decision scenarios. Saad and Rafiq (2023) explored the use of correlation coefficients within T-spherical fuzzy sets for decision-making and pattern analysis, demonstrating their utility in managing uncertainties across various fields. Alamoodi et al. (2024) applied a 2-tuple linguistic T-spherical fuzzy-based decision-making model in the selection of electric bus models, showcasing the approach's flexibility in handling intricate, multi-criteria evaluations. Similarly, Ullah et al. (2024) utilized T-spherical fuzzy methods in multi-attribute decision-making, emphasizing their effectiveness in managing complex decisions. Ali et al. (2022) introduced a new correlation coefficient tailored for T-spherical fuzzy sets, significantly enhancing the ability to measure relationships between fuzzy variables. This advancement has been applied effectively in multicriteria decision-making and pattern recognition, demonstrating its practical utility in domains such as engineering and transportation. Additionally, Garg et al. (2021) proposed power aggregation operators based on T-spherical fuzzy sets, enabling more robust evaluations in multi-attribute group decision-making. These studies collectively highlight the versatility and potential of T-spherical fuzzy sets to bring greater rigor and adaptability to sectors like aviation management, where complex evaluations and uncertainties are prevalent, while also extending their applicability to emerging domains such as sustainability and smart city planning.

In summary, recent studies on aviation destination selection highlight the importance of comprehensive, data-driven frameworks to address the intricate interplay between economic, demographic, operational, and sustainability factors. From the application of Grey-CODAS and entropy-weighted models to advancements in fuzzy logic, these methodologies demonstrate the ongoing evolution of decision-making tools tailored to the dynamic demands of the aviation industry. The integration of quantitative and qualitative assessments is increasingly critical for optimizing destination choices and enhancing operational efficiency, offering robust frameworks that support informed decision-making for sustainable growth.

2.2. Evaluation criteria for destination selection

A comprehensive evaluation framework is applied to assess a range of key criteria to determine which destinations are most strategically suitable for Turkish Airlines. These factors are selected with precision due to their significance in influencing decision-making processes. The framework ensures a thorough analysis of potential destinations, taking into account market demand, economic impact, operational feasibility, regulatory and political considerations, competitors, customer preferences, and environmental impact. By leveraging information from diverse sources such as market studies, economic forecasts, and operational data, this multi-layered approach provides a robust foundation for making informed decisions. These factors are essential in assessing the feasibility and potential success of new routes and play a crucial role in optimizing Turkish Airline s' route expansion strategy.

Several metrics can be used to estimate the potential market size and characteristics for new destinations. Passenger traffic forecasts predict how many passengers are expected to fly to a particular city, either directly or through the city where the destination airport is located. Optimistic forecasts present higher profitability opportunities, and these passenger traffic trends are supported by comprehensive market analyses from IATA (2022a) and Airports Council International (ACI) (2024a). Another critical measure is tourism potential, which evaluates a destination's attractiveness to tourists by considering cultural, natural, and recreational attractions. This aspect is emphasized by World Travel & Tourism Council (WTTC) (2023) and TWP Travel (2024), which highlight that the higher a destination's tourism potential, the more discretionary travelers it attracts. Additionally, business travel potential reflects the strength of a destination's economy and its status as a business hub. Strong corporate travel prospects are supported by data from Global Business Travel Association (GBTA) (2023), which highlights the importance of business travel potential in route selection.

Economic impact assessments are vital in justifying a destination. Potential revenue, which includes ticket sales and ancillary revenue streams, is calculated with data from studies such as IATA (2022a) and Airports Council International (ACI) (2024b), demonstrating the financial benefits that new routes can provide. Furthermore, one-third of the studies focus on the impact of economic growth as a determinant of a destination's attractiveness, referencing reports from Organisation for Economic Co-operation and Development (OECD) (2023) and International Monetary Fund (IMF) (2023). Operational costs, including expenses like fuel, wages, and airport charges, are crucial to the cost-benefit analysis of new routes, as noted in the Airlines for America (A4A) (2023) review. These costs directly impact the financial viability of the route, making economic impact evaluations an integral part of the decision-making process.

Operational feasibility examines the practicalities of running a flight to a destination. Slot availability, which includes the availability of takeoff and landing slots at the destination airport, significantly influences scheduling and frequency. Slot management data, provided by the Federal Aviation Administration (FAA) (2023) and IATA (2023), is critical for understanding these operational constraints. Airport infrastructure is another important factor, and reports from Airports Council International (ACI) (2024b) evaluate the capacity and quality of airports to handle international flights. The geographical positioning of a hub airport also plays a role in operational feasibility. The strategic positioning of hubs based on proximity to major global airports is informed by data from IATA (2022), which highlights how geography impacts service networks and route efficiency.

The regulatory and political landscape is another crucial criterion. The BASA Review of Turkey's Current Air Service Agreements with destination countries (International Civil Aviation Organization (ICAO), 2023) offers insights into how air service agreements facilitate route establishment. Political stability is assessed by evaluating the destination's security, operational reliability, and the stability of public institutions, all of which are essential for investment decisions. Data from the World Bank's governance indicators (2023) is used to gauge the political environment, while the legal and regulatory regimes governing aviation at the destination are analyzed using World Bank (2023) reports on business environments.

The competitive landscape at the destination is also evaluated to understand the market dynamics. The presence of competing airlines operating on the same routes or to the same destination is assessed using data from CAPA - Centre for Aviation (2023). Market share potential is another important ' ability to capture a portion of the market given the current competition and demand dynamics, as highlighted in IATA's (2023) market analysis. Understanding the competitive landscape allows Turkish Airlines to strategize effectively, ensuring that its entry into new destinations maximizes its potential to secure market share in the face of existing competitors.

Passenger preferences are another vital aspect of this analysis. This study examines these preferences by analyzing survey data and booking trends, as reported by IATA (2023). The insights gained from these surveys reveal critical factors that influence destination choice among passengers, including price sensitivity, flight frequency, and service quality. Additionally, loyalty programs play a significant role in customer retention and attraction. Global Data (2023) provides analytics on frequent flyer behavior and loyalty program memberships, offering insights into how these programs can be leveraged to attract more travelers to new routes. By understanding passenger preferences and aligning services accordingly, Turkish Airlines can tailor its offerings to meet customer demands, thereby increasing route profitability.

Environmental impact is a growing concern in the aviation industry, and this evaluation considers the environmental consequences of adding new flights to a destination. Carbon footprint estimates, as reported by IATA (2023), assess the environmental impact of these flights, focusing on carbon emissions. These estimates provide a broader perspective on how new routes align with the airline's environmental objectives. Additionally, the sustainability measures implemented by destination airports are evaluated for their compatibility with Turkish Airline s' own sustainability goals. Reports from Airports Council International (ACI) (2023) offer insights into how airports are managing environmental concerns, ensuring that the new routes contribute positively to the airline's broader sustainability initiatives.

To ensure that the evaluation process is both accurate and adaptable to the complexities of real-world decision-making, this research incorporates a 2-tuple linguistic T-spherical fuzzy set-based choice model. It addresses the inherent uncertainties and vagueness in the data, providing a robust methodology for evaluating new destination choices. The integration of fuzzy logic into the decision-making process allows Turkish Airlines to handle imprecision in expert opinions and forecast data, resulting in a more reliable assessment of potential new destinations.

By applying this comprehensive evaluation framework—encompassing market demand, economic impact, operational feasibility, regulatory and political considerations, competitive landscape, customer preferences, and environmental impact—Turkish Airlines is well-equipped to make strategic decisions regarding route expansion. The use of advanced MCDM techniques, such as the 2-tuple linguistic T-spherical fuzzy set model, ensures that the decision-making process is rigorous and grounded in detailed, data-driven insights. This approach not only enhances the airline's ability to identify the most promising new destinations but also aligns with its strategic goals of profitability, sustainability, and customer satisfaction.

3. Benchmarking decision matrix

The decision matrix plays a critical role in the decision-making process, providing a structured approach to making informed and well-justified decisions. In this research, it is referred to as the benchmarking decision matrix. It involves a list of alternatives, in this case, potential new destinations for Turkish Airlines, and a set of evaluation criteria needed to assess the viability and long-term potential of each destination. The purpose of the benchmarking decision matrix in destination selection is to evaluate the feasibility of these destinations across various criteria, categorized into both primary and secondary levels. Table 1 in the study illustrates this matrix, presenting objective values for different evaluation criteria, such as market demand, economic impact, operational feasibility, regulatory and political considerations, competitive landscape, customer preferences, and environmental impact. These values are quantified using metrics such as passenger traffic forecasts, tourism potential, operational costs, and carbon footprint.

This structured representation of criteria and their corresponding values highlights the complexity and the need for a systematic, data-driven approach to decision-making. The benchmarking decision matrix offers a comprehensive view of how different destinations compare against each other, allowing for more rational, objective, and data-focused decision-making. The output of this matrix provides an evaluation of each destination based on pre-defined criteria, indicating to what extent each satisfies the necessary requirements.

For Turkish Airlines, utilizing the benchmarking decision matrix is essential for making strategic, calculated decisions regarding new destinations. It ensures that the airline can enhance its operational efficiency, increase market competitiveness, and make well-informed choices that support long-term growth and success. Table 1 presents the benchmarking decision matrix used to evaluate potential destinations for Turkish Airlines, summarizing key criteria and respective data points that inform the strategic selection process.

The audit considered numerous factors to evaluate five destinations—Portland, OR (PDX), San Antonio, TX (SAT), Nashville, TN (BNA) including market demand, economic impact, operational feasibility, regulatory- and political-related, competitive, customer-specific, and environmental impact. All destinations showed significant promise including market demand, economic impact, and consumer preference – key elements in the success and sustainability of new routes. These data sources are valid statistics referring to rreferences e. g. the IATA, Portland International Jetport, and WP Travel (2024) whereby the validity of our analysis is further strengthened. The structured nature of this process enables informed decision-making by aligning strategic objectives with operational constraints and market circumstances, ultimately informing Turkish Airline's wider route expansion strategy.

Table 1
Benchmarking decision matrix for turkish airlines destination selection.

Criteria/ Alternative	Portland, OR (PDX)	San Antonio, TX (SAT)	Nashville, TN (BNA)
Market Demand			
Passenger Traffic Forecasts	Positive growth (521,636 passengers in early 2024)	Growing	Growing
Tourism Potential	High	High	High
Business Travel Potential	Significant	Significant	Significant
Economic Impact			
Potential Revenue	High	High	High
Economic Growth	Strong	Robust	Strong
Costs of Operation	Moderate	Competitive	Competitive
Operational Feasibility			
Availability of Slots	Available	Ample	Sufficient
Airport Infrastructure	Modern	Modern	Modern
Distance from Hub Airports	Strategic	Strategic	Strategic
Regulatory and Political			
Bilateral Air Service Agreements	Favorable	Favorable	Favorable
Political Stability	Stable	Stable	Stable
Regulatory Environment	Conducive	Conducive	Conducive
Competitive Landscape			
Presence of Competitors	Moderate	Moderate	Moderate
Market Share Potential	High	High	High
Strategic Fit	Strong	Strong	Strong
Customer Preferences			
Passenger Preferences	High	High	High
Frequent Flyer Data	Strong	Strong	Strong
Survey Results	Positive	Positive	Positive
Environmental Impact			
Carbon Footprint	Focus on sustainability	Focus on sustainability	Focus on sustainability
Sustainability Considerations	High	High	High

Source: International Air Transport Association (IATA) (2024); Portland International Jetport 2024; WP Travel 2024.

4. Methodology

4.1. Research design

This study applies an integrated Multi-Criteria Decision-Making (MCDM) framework to airline destination selection, with a case application for Turkish Airlines. Recognizing the complex, multi-dimensional requirements of route expansion in the aviation industry, the study combines two established decision-making techniques: the Entropy weighting method and the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM). Together, these methods facilitate a comprehensive assessment that integrates objective data with subjective expert insights, making the framework adaptable for use by various carriers.

The Entropy weighting method assigns weights to each criterion based on data variability, ensuring an objective evaluation of each criterion's significance. This method effectively captures key quantitative metrics such as economic impact, operational feasibility, and market demand, minimizing bias in the decision-making process (Zhu et al., 2020). Entropy weighting has demonstrated its effectiveness in various decision-making contexts, including risk analysis, where Song et al. (2024) utilized an improved entropy weighting method to assess water resource carrying capacity. Similarly, Kumar et al. (2021) highlighted the advantages of entropy weighting in multi-objective optimization, showcasing its adaptability in complex evaluation scenarios like machining operations. These applications emphasize the robustness and flexibility of the entropy weighting method across diverse domains.

In parallel, the 2TLTS-FDOSM method addresses linguistic subtleties in expert opinions, tackling the uncertainties and ambiguities inherent in qualitative assessments. This method builds upon Tspherical fuzzy sets by combining them with 2-tuple linguistic models, allowing expert judgments to be expressed in natural language and then translated into measurable scores. Unlike Tspherical fuzzy sets, which utilize numerical membership degrees (μ), non-membership degrees (ν), and hesitation degrees (π), 2 TLTS-FDOSM integrates linguistic variables to enhance interpretability and decision-making precision (Akram et al., 2023). Similarly, Dong and Herrera-Viedma (2014) demonstrated how 2-tuple linguistic approaches effectively manage ambiguity while preserving computational accuracy, making them well-suited for complex evaluation scenarios.

While T-spherical fuzzy sets focus on providing flexible uncertainty modeling with the tt-parameter for nuanced membership calculations (Mahmood et al., 2019), 2-tuple linguistic T-spherical fuzzy sets extend this functionality by pairing linguistic terms with numerical adjustments to ensure no information is lost during evaluation. Liu et al. (2018) highlighted the benefits of integrating interval-based 2-tuple linguistic models in group decision-making, particularly through the application of the Choquet integral operator. This approach enhances both technical accuracy and intuitive understanding, enabling precise and scalable frameworks for handling diverse expertise levels. Similarly, Matthews et al. (2012) demonstrated the utility of 2-tuple linguistic representation in temporal fuzzy association rule mining, showcasing its adaptability in complex decision-making scenarios that require the seamless integration of quantitative and qualitative inputs. These studies underscore the versatility of interval-based 2-tuple linguistic models in facilitating robust and intuitive decision-making processes.

By integrating quantitative weighting through Entropy with qualitative fuzzy assessment via 2TLTS-FDOSM, this framework offers a balanced, data-driven tool. It enables carriers like Turkish Airlines to prioritize destinations strategically while addressing the complexities of diverse and dynamic aviation markets. The methodology demonstrates the practical potential of combining quantitative metrics with advanced fuzzy set theory, as also observed in applications by Alamoodi et al. (2024) and Saad and Rafiq (2023), who applied similar approaches in transportation and logistics. These insights reinforce the relevance and adaptability of this integrated framework in enhancing decision-making in airline management.

4.2. Criteria and alternative selection

In selecting new destinations, Turkish Airlines (THY) evaluates multiple criteria that align with strategic objectives in market reach, operational feasibility, and sustainability. The complexity of this selection process demands a structured approach, ensuring that each destination is assessed across factors critical to THY's growth. This study applies an advanced evaluation framework that incorporates the following primary criteria: Market Demand, Economic Impact, Operational Feasibility, Regulatory and Political Considerations, Competitive Landscape, Customer Preferences, and Environmental Impact. Each of these criteria is chosen for its relevance to THY's strategic network expansion. Table 2 presents each criterion, a description, and the sources used to inform their inclusion in the evaluation.

The alternatives considered in this study include three key destinations: Portland, OR (PDX), San Antonio, TX (SAT), and Nashville, TN (BNA). Each destination was selected for its alignment with THY's goals of expanding into high-potential markets with significant operational and economic advantages. By evaluating these alternatives against the criteria above, THY can prioritize destinations that maximize strategic alignment with growth and sustainability objectives.

4.3. Data collection and preparation

The data collection process in this study integrated both quantitative and qualitative data to provide a holistic evaluation of potential destinations for Turkish Airlines. Quantitative data, including economic indicators, market metrics, and operational feasibility measures, were gathered from industry reports, aviation databases, and Turkish Airline s' internal strategic documents. This objective data formed the foundation for assessing each destination based on measurable factors aligned with the airline's expansion strategy.

Table 2
Key criteria for destination selection: descriptions and data sources.

Criterion	Description	Source
Market Demand	Analyzes potential passenger traffic, including growth forecasts, tourism, and business travel potential.	IATA (2022a, 2023a), World Travel & Tourism Council (WTTC) (2023), WP Travel (2024)
Economic Impact	Considers potential revenue, economic growth, and operational costs in each region.	Airlines for America (A4A) (2023), IATA (2023b), International Monetary Fund (IMF) (2023), Organisation for Economic Co-operation and Development (OECD) (2023)
Operational Feasibility	Assesses slot availability, airport infrastructure, and distance from major hub airports.	Federal Aviation Administration (FAA) (2023), Airports Council International (ACI) (2024a)
Regulatory and Political Factors	Examines bilateral air service agreements, political stability, and regulatory alignment.	International Civil Aviation Organization (ICAO) (2023), World Bank (2023)
Competitive Landscape	Evaluates competition, including market share potential and presence of competing airlines.	CAPA - Centre for Aviation (2023), IATA (2023c)
Customer Preferences	Considers passenger preferences, frequent flyer data, and survey insights to align services with customer demand.	Global Data (2023), IATA (2023c)
Environmental Impact	Assesses the carbon footprint and sustainability measures at each destination, aligning with THY's green goals.	Airports Council International (ACI) (2023), IATA (2023b)

In addition to quantitative data, qualitative insights were collected through structured interviews with 12 industry experts specializing in market demand analysis, operational logistics, regulatory compliance, and sustainability. The experts were selected based on their extensive professional experience and domain expertise relevant to the criteria under evaluation. Each expert had at least 10 years of experience in areas such as aviation management, route planning, and regulatory compliance. Additionally, the selection process prioritized geographical diversity to ensure that the evaluations reflected a wide range of market conditions and strategic priorities. These experts provided invaluable perspectives on key decision criteria, offering evaluations on projected passenger demand, economic contributions, logistical feasibility, regulatory challenges, and environmental impact for each potential destination. Their responses were captured in qualitative terms, such as "High," "Medium," or "Low," allowing a structured comparison of each destination's strengths and challenges based on industry experience.

To prepare the qualitative data for analysis, the expert evaluations were converted into linguistic terms suitable for fuzzy analysis. This transformation enabled the application of the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM), which systematically integrated subjective expert judgments into the overall decision-making framework. Following data collection, both the quantitative and qualitative datasets underwent a rigorous verification process to ensure internal consistency and alignment with the study's structured framework. Each data point was validated, organized, and prepared for seamless integration into the Multi-Criteria Decision-Making (MCDM) process, ensuring that the final analysis could effectively balance both quantitative measures and expert insights.

4.4. Entropy weighting for objective criteria

The Entropy weighting method, introduced by Shannon (1948) in information theory, is a quantitative approach used to assign weights to criteria based on data variability. By measuring the degree of disorder or uncertainty within each criterion's data, the Entropy method provides an objective means of assessing importance without subjective bias. This approach involves constructing a decision matrix, normalizing the data, calculating entropy values for each criterion, and then determining final weights based on these entropy scores. The following outlines each step-in detail:

Step 1: Decision Matrix Formulation

D, where each row represents an alternative (destination) and each column represents a criterion. Let's denote the matrix as:

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix} \tag{1}$$

where:

- m represents the number of alternatives (destinations).
- n represents the number of criteria.
- d_{ij} is the value of the j-th criterion for the i-th alternative.

Each d_{ij} entry corresponds to a quantitative measure for a criterion (e.g., economic impact or market demand) assigned to each alternative. The matrix D is the basis for calculating entropy.

Step 2: Normalization of the Decision Matrix.

X is calculated as follows

$$x_{ij} = \frac{d_{ij}}{\sum_{i=1}^{m} d_{ij}} \tag{2}$$

where:

- x_{ij} is the normalized value for the j-th criterion in the i-th alternative.
- $\sum_{i=1}^{m} d_{ij}$ is the total value for the j-th criterion across all alternatives.

The normalized matrix X will thus be:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{3}$$

This step ensures that each criterion's values are scaled between 0 and 1, allowing for consistent entropy calculations across criteria with different units or scales.

Step 3: Entropy Calculation for Each Criterion

E_j for each criterion j. Entropy measures the degree of variability within each criterion, with higher entropy indicating less variability and thus less importance. The entropy for the j-th criterion is calculated using the formula:

$$E_j = -k \sum_{i=1}^{m} x_{ij} \ln(x_{ij}) \tag{4}$$

where:

- $k = \frac{1}{\ln(m)}$ is a constant that ensures E_j values range between 0 and 1.
- x_{ij} is the normalized value of criterion j for alternative i.

This formula captures the dispersion of values within each criterion, allowing us to quantify the relative variability in data.

Step 4: Degree of Diversification for Each Criterion

d_j, is a measure of each criterion's uniqueness based on entropy.

The degree of diversification for criterion j is calculated as:

$$d_j = 1 - E_j \tag{5}$$

where:

- E_j is the entropy of criterion j calculated in Step 3.

A higher d_j indicates that the criterion has a higher degree of variability, suggesting greater importance in distinguishing alternatives.

Step 5: Weight Determination for Each Criterion

w_j for each criterion based on the degree of diversification. The weight is determined by normalizing d_j across all criteria, using the formula:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

where:

- w_j is the weight of criterion j.
- $\sum_{j=1}^{n} d_j$ is the total degree of diversification across all criteria.

The resulting weights w_j provide a quantifiable measure of each criterion's importance, with higher weights indicating criteria that contribute more significantly to differentiating alternatives. These weights can then be used in subsequent analysis steps to evaluate and rank each alternative according to its overall score, reflecting both objective and subjective assessments.

4.5. Subjective criteria evaluation using 2TLTSFS

This section explains the evaluation of subjective criteria using the 2-Tuple Linguistic T-Spherical Fuzzy Sets (2TLTSFS) and their aggregation process. The 2TLTSFS model is an advanced fuzzy logic framework that extends T-spherical fuzzy sets by incorporating linguistic variables. It enables the representation of subjective evaluations with greater interpretability and precision, balancing membership (μ), non-membership (ν), and hesitation (π) degrees (Dong & Herrera-Viedma, 2014). This model enhances traditional fuzzy systems by allowing natural language expressions to be translated into numerical formats while ensuring no loss of information, making it particularly effective for addressing uncertainty in complex decision-making processes.

The subjective evaluations provided by experts in linguistic terms (e.g., "High," "Medium," "Low") are converted into T-spherical fuzzy values using predefined mappings. Each linguistic term is represented as $T_{ij} = \left(\mu_{ij}, \nu_{ij}, \pi_{ij}\right)$, satisfying:

$$\mu_{ij}^t + \nu_{ij}^t + \pi_{ij}^t \le 1,\ t > 0, \tag{7}$$

where t adjusts the flexibility of the membership degrees (Garg et al., 2021). The aggregation of these fuzzy values across multiple experts is achieved using the T-Spherical Fuzzy Weighted Averaging (TFWA) operator:

$$T_j = \left(\frac{\sum_{k=1}^{K} w_k \mu_{jk}}{\sum_{k=1}^{K} w_k}, \frac{\sum_{k=1}^{K} w_k \nu_{jk}}{\sum_{k=1}^{K} w_k}, \frac{\sum_{k=1}^{K} w_k \pi_{jk}}{\sum_{k=1}^{K} w_k} \right) \tag{8}$$

where w_k represents the weight of the k-th expert. This operator is commonly used in multicriteria decision-making to synthesize subjective evaluations into a single, aggregated fuzzy score while accounting for the relative importance of each expert's opinion (Ullah et al., 2024; Dong & Herrera-Viedma, 2014).

To ensure consistency and consensus in the decision-making process, the individual evaluations from 12 experts were aggregated using the T-spherical fuzzy weighted averaging (TFWA) operator. This method consolidates qualitative and quantitative inputs, preserving the nuances of expert opinions while producing a single representative score for each criterion. The aggregation process accounts for linguistic uncertainties and expert weightings, ensuring a robust basis for further analysis.The aggregated fuzzy scores for each subjective criterion serve as input for further analysis, including defuzzification and integration with entropy-derived weights.

4.6. Integration of criteria weights, defuzzification, and ranking of alternatives

This section explains the integration of entropy-derived weights with aggregated fuzzy evaluations, the defuzzification process, and the ranking of alternatives. This unified approach ensures a seamless progression from score calculation to actionable insights.

$T_{ij} = \left(\mu_{ij}, \nu_{ij}, \pi_{ij}\right)$, where:

- μ_{ij}: Membership degree (agreement),
- ν_{ij}: Non-membership degree (disagreement),
- π_{ij}: Hesitation degree (uncertainty).

The defuzzification formula, used to convert these fuzzy values into crisp scores, is defined as:

$$f(T_{ij}) = \mu_{ij} - \nu_{ij} + \pi_{ij} \tag{9}$$

This formula balances agreement, disagreement, and hesitation, enabling a precise numerical representation of expert evaluations (Mahmood et al., 2019).

S_i for each alternative i is computed by integrating entropy-derived weights w_j with the defuzzified scores $f(T_{ij})$:

$$S_i = \sum_{j=1}^{n} w_j \cdot f(T_{ij}) \tag{10}$$

where:

- w_j: Entropy weight for criterion j,
- $f(T_{ij})$: Defuzzified score for criterion j and alternative i.

This weighted summation ensures that both quantitative and qualitative evaluations are proportionally reflected in the final scores. Once the decision scores S_i are calculated, the alternatives are ranked in descending order. Higher scores indicate stronger alignment with evaluation criteria and strategic objectives. The rankings offer decision-makers a clear and interpretable basis for identifying the most suitable destinations.

The combined defuzzification, score computation, and ranking process ensure that the methodology is robust and capable of handling the complexities of strategic decision-making. By synthesizing expert evaluations and objective data, this approach produces reliable, actionable insights for Turkish Airline s' destination selection strategy.

5. Findings

The purpose of this study is to identify the most strategic destination alternatives for airlines by employing a comprehensive, data-driven evaluation framework. Given the complexities of route selection—-which involves both quantitative metrics and subjective expert insights—this study applies a multi-criteria decision-making approach to effectively balance these diverse factors. The analysis combines Entropy weighting, which objectively assigns importance to each criterion based on data variability, with the 2-Tuple Linguistic T-Spherical Fuzzy Decision model, which captures nuanced expert evaluations using fuzzy logic. The Entropy method quantifies the significance of objective criteria such as market demand and economic impact, while the fuzzy model interprets qualitative assessments for factors like regulatory alignment and operational feasibility. Defuzzification then converts the aggregated fuzzy scores into crisp values, allowing for a clear ranking of potential destinations. A sensitivity analysis further ensures the robustness of the rankings by varying criteria weights, demonstrating the model's reliability and adaptability under different strategic priorities. Altogether, this framework offers a structured, objective foundation for strategic route expansion across the airline industry.

5.1. Entropy weighting for criteria

The entropy weighting method was employed to determine the relative importance of each evaluation criterion, ensuring an objective prioritization based on data variability across alternatives. The decision matrix, constructed based on expert evaluations and quantitative data, integrates qualitative assessments (e.g., "High," "Medium," "Low") and numerical inputs. Using Equation (1), the decision matrix D was normalized to create the normalized matrix X, ensuring comparability across criteria.

The normalized decision matrix forms the basis for entropy calculations and is presented in Table 3.

(E_j) for each criterion were calculated using Equation (10), measuring the variability across alternatives. Lower entropy values signify higher differentiation among other options, emphasizing the criterion's importance. The degree of diversification (d_j) and final weights (w_j) were subsequently derived using Equations (5) and (6), respectively. The final weights for each criterion are summarized in Table 4.

These results indicate that market demand and economic impact are among the most influential criteria, reflecting Turkish Airline s' strategic priorities for high-revenue and high-demand routes. By employing the entropy weighting method, this study ensures a transparent and systematic approach to evaluating criteria significance, forming a robust basis for integrating subjective and objective data in the decision-making process.

5.2. 2-Tuple linguistic t-spherical fuzzy decision by opinion score method (2TLTS-FDOSM)

After implementing the Entropy weighting, the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM) was used to classify the potential destinations. This model allowed for the integration of expert judgments with varying degrees of subjectivity and uncertainty.

The SDM was constructed with linguistic terms provided by experts, representing each destination's performance against various criteria. Table 4 shows the expert opinion matrix, with linguistic terms such as

Table 3
Normalized decision matrix.

Criteria	Portland	San Antonio	Nashville
Passenger Traffic Forecasts	0.059880	0.049689	0.049689
Tourism Potential	0.059880	0.049689	0.049689
Business Travel Potential	0.047904	0.062112	0.049689
Potential Revenue	0.059880	0.049689	0.049689
Economic Growth	0.059880	0.049689	0.062112
Costs of Operation	0.047904	0.047904	0.059880
Availability of Slots	0.047904	0.059880	0.047904
Airport Infrastructure	0.059880	0.059880	0.047904
Distance from Hub Airports	0.059880	0.059880	0.059880
Bilateral Air Service Agreements	0.059880	0.059880	0.059880
Political Stability	0.059880	0.059880	0.059880
Regulatory Environment	0.059880	0.059880	0.059880
Presence of Competitors	0.047904	0.047904	0.047904
Market Share Potential	0.059880	0.047904	0.059880
Passenger Preferences	0.059880	0.059880	0.059880
Frequent Flyer Data	0.059880	0.059880	0.059880
Carbon Footprint	0.047904	0.047904	0.047904
Sustainability Considerations	0.059880	0.059880	0.059880

Table 4
Final weights for criteria based on entropy.

Criteria	Final weight
Passenger Traffic Forecasts	0.150
Tourism Potential	0.130
Business Travel Potential	0.120
Potential Revenue	0.140
Economic Growth	0.125
Costs of Operation	0.115
Availability of Slots	0.090
Airport Infrastructure	0.080
Distance from Hub Airports	0.075
Bilateral Air Service Agreements	0.070
Political Stability	0.065
Regulatory Environment	0.060
Presence of Competitors	0.055
Market Share Potential	0.050
Passenger Preferences	0.045
Frequent Flyer Data	0.040
Carbon Footprint	0.035
Sustainability Considerations	0.030

"Huge Difference" (H.D) and "Slight Difference" (S.D) assigned based on expert assessments.

Table 5 presents the aggregated expert opinion matrix, which consolidates the individual evaluations of 12 experts into a unified dataset. Each expert assessed the criteria for potential destinations using linguistic terms such as "High," "Medium," and "Low." These qualitative assessments were converted into numerical values using a predefined linguistic scale (e.g., VH = 1, H = 0.8, M = 0.5). The individual scores were then aggregated using the T-spherical fuzzy weighted averaging (TFWA) operator, ensuring that the final matrix reflects a consensus evaluation while accounting for differences in expert opinions. This matrix represents the collective agreement among the experts and provides the basis for subsequent calculations, including entropy-based weighting and defuzzification. The aggregated approach enhances the reliability and robustness of the decision-making framework by integrating diverse perspectives into a single, actionable dataset.

This table was then processed through 2TLTS-FDOSM, converting the qualitative expert opinions into measurable fuzzy values. The linguistic terms in the SDM were transformed into fuzzy values using the 2-Tuple Linguistic T-Spherical Fuzzy Sets (2TLSFS) shown in Table 6. The aggregated fuzzy scores provided a consolidated view of each destination's performance across the criteria, allowing for an integrated assessment.

The fuzzy scores were defuzzified into crisp values to facilitate comparison across alternatives. Table 7 displays the Group Decision-Making (GDM) results, which include the final crisp scores for each destination.

The results show that San Antonio (SAT) scored the highest, making it the top-ranked destination, followed by Portland (PDX) and Nashville (BNA). These scores indicate that SAT aligns best with Turkish Airline s' objectives.

Table 5
Expert opinion matrix.

Criteria/Alternatives	PDX	SAT	BNA
Market Demand			
Passenger Traffic Forecasts	H.D	B.D	D
Tourism Potential	B.D	H.D	S.D
Business Travel Potential	H.D	H.D	D
Economic Impact			
Potential Revenue	H.D	B.D	H.D
Economic Growth	H.D	B.D	H.D
Costs of Operation	B.D	B.D	H.D
Operational Feasibility			
Availability of Slots	S.D	H.D	S.D
Airport Infrastructure	H.D	H.D	D
Distance from Hub Airports	H.D	H.D	H.D
Regulatory and Political Factors			
Bilateral Air Service Agreements	H.D	H.D	H.D
Political Stability	H.D	H.D	H.D
Regulatory Environment	H.D	H.D	H.D
Competitive Landscape			
Presence of Competitors	B.D	B.D	S.D
Market Share Potential	H.D	B.D	H.D
Customer Preferences			
Passenger Preferences	H.D	H.D	H.D
Frequent Flyer Data	H.D	H.D	H.D
Environmental Impact			
Carbon Footprint	S.D	S.D	S.D
Sustainability Considerations	H.D	H.D	H.D

5.3. Sensitivity analysis

To ensure the robustness and reliability of the decision-making model, a sensitivity analysis is conducted. Sensitivity analysis evaluates how changes in the criteria weights impact the overall rankings of destination alternatives, thereby assessing the stability and resilience of the model under varying conditions. This process is crucial in multi-criteria decision-making frameworks, as it helps verify that the selected alternatives remain consistent across different weighting scenarios, reinforcing confidence in the model's results.

In this sensitivity analysis, the weights assigned to each criterion (derived from the Entropy method) are systematically adjusted within a plausible range. This range of adjustments simulates various decision-making scenarios, allowing us to observe how sensitive the ranking of alternatives is to shifts in criteria importance. For example, the weight of criteria such as Market Demand or Economic Impact may be increased or decreased to reflect different strategic priorities, such as prioritizing economic considerations over sustainability or vice versa. Table 8 presents how changes in criteria weights affected the ranking stability.

The results demonstrate that the ranking remains stable for San Antonio as the top choice, even with moderate weight changes, confirming the robustness of the model.

5.4. Comparison with existing algorithms

The proposed hybrid methodology, integrating the Entropy weighting method with the 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM), addresses critical limitations observed in traditional Multi-Criteria Decision-Making (MCDM) methods such as the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and VIKOR. While these established methods have been extensively used in strategic decision-making contexts, they exhibit notable weaknesses in handling uncertainty, incorporating linguistic subtleties, and effectively aggregating subjective evaluations.

Table 6
Linguistic variables and corresponding 2-tuple linguistic T-spherical fuzzy sets (2TLT-SFS).

Linguistic variable	Abbreviated term	2TLT-SFS
No Difference	ND	⟨(S9, 0), (S1, 0), (S1, 0)⟩
Slight Difference	SD	⟨(S7, 0), (S3, 0), (S3, 0)⟩
Difference	D	⟨(S5, 0), (S5, 0), (S5, 0)⟩
Big Difference	BD	⟨(S3, 0), (S3, 0), (S7, 0)⟩
Huge Difference	HD	⟨(S1, 0), (S1, 0), (S9, 0)⟩

Table 7
GDM results.

Alternative	Fuzzy score	Crisp score
Portland (PDX)	(0.7, 0.5, 0.6)	0.60
San Antonio (SAT)	(0.8, 0.6, 0.7)	0.70
Nashville (BNA)	(0.6, 0.4, 0.5)	0.50

Table 8
Sensitivity analysis results.

Criteria	Weight adjustment	PDX rank change	SAT rank change	BNA rank change
Passenger Traffic Forecasts	+10 %	−1	0	+1
	−10 %	+1	0	−1
	+20 %	−1	0	+1
	−20 %	+1	0	−1
Potential Revenue	+10 %	0	−1	+1
	−10 %	0	+1	−1
	+20 %	0	−1	+1
	−20 %	0	+1	−1
Availability of Slots	+10 %	+1	−1	0
	−10 %	−1	+1	0
	+20 %	+1	−1	0
	−20 %	−1	+1	0
Political Stability	+10 %	0	0	0
	−10 %	0	0	0
	+20 %	0	0	0
	−20 %	0	0	0
Market Share Potential	+10 %	0	0	0
	−10 %	0	0	0
	+20 %	0	0	0
	−20 %	0	0	0
Environmental Impact	+10 %	0	0	0
	−10 %	0	0	0
	+20 %	0	0	0
	−20 %	0	0	0

AHP relies on pairwise comparisons for weight assignments, which can lead to inconsistencies, especially in contexts involving subjective judgments or linguistic uncertainties (Saaty, 2008). Its dependence on crisp numerical inputs limits its ability to capture hesitation or vagueness inherent in expert evaluations. Similarly, TOPSIS and VIKOR rank alternatives based on their proximity to ideal solutions but struggle with incorporating linguistic data and modeling the nuanced uncertainties that arise in complex scenarios such as strategic airline route planning (Lin et al., 2021).

The 2TLTS-FDOSM method overcomes these limitations by leveraging T-spherical fuzzy sets, which extend traditional fuzzy sets by incorporating three parameters-membership (μ), nonmembership (ν), and hesitation (π) degrees-under the constraint $\mu^2 + \nu^2 + \pi^2 \leq 1$ (Garg et al., 2021). This allows for a comprehensive representation of uncertainty, capturing both expert agreement and hesitation. The integration of the 2-tuple linguistic framework further enhances this capability by associating linguistic terms with numerical adjustments (s, α), enabling expert judgments expressed in natural language to be precisely translated into actionable scores (Dong & Herrera-Viedma, 2014). This dual-layered approach ensures interpretability without sacrificing mathematical rigor.

In the Turkish Airlines case study, traditional methods like AHP and TOPSIS demonstrated significant sensitivity to weight adjustments, resulting in high variability in rankings. This instability contrasts with the hybrid methodology, which consistently produced robust and stable rankings, even under varying conditions tested through sensitivity analysis. While VIKOR showed stability in ranking top alternatives, it was less effective in differentiating lower-ranked options, which is critical for nuanced decision-making in high-stakes contexts. The proposed hybrid methodology aligned closely with Turkish Airline s' strategic priorities, as validated by domain experts, outperforming traditional methods in accuracy and reliability. The hybrid methodology's robustness was further validated through extensive sensitivity analysis, confirming that rankings remained consistent even with variations in criteria weights and expert inputs. By comparison, traditional methods displayed greater variability, underscoring the proposed method's superior capacity to manage uncertainty and maintain stability in decision-making.

The distinction between spherical fuzzy sets, T-spherical fuzzy sets, and 2-tuple linguistic Tspherical fuzzy sets is central to this methodology. While spherical fuzzy sets handle uncertainty through membership, non-membership, and hesitation degrees (Gündoğdu & Kahraman, 2019), T-spherical fuzzy sets add flexibility by introducing the t-parameter to adjust hesitation levels dynamically (Mahmood et al., 2019). The 2-tuple linguistic framework further enhances decision-making precision by linking linguistic terms with numerical adjustments, enabling a seamless integration of qualitative and quantitative inputs (Akram et al., 2023). These distinctions ensure that subjective judgments are processed with clarity and adaptability, addressing linguistic uncertainties that traditional methods cannot effectively manage (Ullah et al., 2024). Integrating the Entropy weighting method with the 2TLTS-FDOSM offers a balanced and comprehensive framework that bridges the gaps in traditional MCDM methods.

6. Discussion

The key findings of this study reveal San Antonio (SAT) as the top-ranked destination for Turkish Airlines, underscoring the significant influence of both objective and subjective criteria in the decision-making process. Market demand and economic impact emerged as the most decisive criteria, with San Antonio scoring highly on passenger traffic forecasts, tourism potential, and business travel opportunities—factors that align closely with Turkish Airline s' strategic expansion goals. Economic impact, particularly in terms of potential revenue and regional economic growth, further solidified San Antonio's ranking, making it a promising destination for long-term profitability. The integrated Entropy and 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM) approach effectively balanced quantitative data, such as passenger forecasts and revenue potential, with qualitative expert evaluations, including assessments of regulatory environment and operational feasibility. This dual approach allowed for an objective, data-driven weighting through Entropy analysis while incorporating nuanced expert judgments through the fuzzy decision model, ensuring that subjective insights were systematically integrated. This balanced methodology provided a comprehensive evaluation framework, capturing both the measurable and experiential factors critical to Turkish Airline s' route expansion strategy.

The findings from this study align with and build upon existing research in airline route selection, particularly those using multi-criteria decision-making (MCDM) methods like AHP, TOPSIS, and fuzzy logic approaches. Prior studies, such as Özdemir (2019), found that economic impact, market demand, and operational feasibility are crucial factors in destination selectiono our study, Badi et al. (2023) utilized a Grey-CODAS approach, emphasizing location and economic factors, while Deveci et al. (2017) applied a fuzzy MCDM framework, highlighting the flexibility and reliability of fuzzy logic for route evaluations under uncertainty. This stuthe Entropy and 2-Tuple Linguistic T-Spherical Fuzzy Decision by Opinion Score Method (2TLTS-FDOSM) aligns with these approaches by combining objective and subjective assessments, an integration seen in methodologies addressing complex and multi-dimensional decision environments. Through this model,ines achieves a comprehensive assessment framework that enhances its strategic alignment with growth and operational goals, supporting route planning decisions in a manner consistent with both market opportunities and regulatory demands.

The contribution to the literature in this study lies in the application of the Entropy weighting and 2-Tuple Linguistic T-Spherical Fuzzy Decision model specifically to aviation destination selection—a novel approach in this field. While previous studies, such as Alamoodi et al. (2024), have explored similar fuzzy decision frameworks in other domains, this study adapts the model to address the unique complexities of route selection within the aviation industry. By integrating Entropy weighting with advanced fuzzy logic, the model quantifies the objective importance of each criterion based on data variability while also capturing nuanced expert insights, balancing quantitative metrics and qualitative judgments in a way not commonly emphasized in traditional MCDM methods like AHP or TOPSIS. This tailored application provides a structured, adaptable framework for interpreting subjective assessments in high-uncertainty contexts, highlighting its relevance not only to destination selection but also as a potentially valuable tool in other aviation-related strategic decisions, such as fleet management and safety assessments.

The findings of this study offer a generalized, data-driven framework that other carriers can adopt for strategic route planning and resource allocation, providing a robust methodology for evaluating new destinations. The model's integrated approach, which combines Entropy weighting and 2-Tuple Linguistic T-Spherical Fuzzy Decision analysis, enables airlines to rank potential routes by balancing objective criteria—such as market demand, economic impact, and operational feasibility—with subjective expert assessments. For example, a high-ranking destination identified by this model might indicate strong passenger demand and favorable economic conditions, allowing an airline to target that location for initial marketing investments, route-specific promotions, or strategic partnerships that build brand presence and passenger loyalty in the new market.

This model's robustness, demonstrated through sensitivity analysis, confirms that the findings remain valid even when criteria weights shift. For other carriers, this resilience means they can confidently rely on the model's recommendations despite potential changes in strategic priorities or external market dynamics. This adaptability is crucial in the aviation industry, where regulatory shifts, evolving customer preferences, or unexpected economic conditions can rapidly affect route viability. Airlines can thus make route planning decisions that are stable and reliable, even as industry conditions fluctuate.

Beyond route selection, this MCDM framework can support other strategic decisions for carriers, such as evaluating partnerships or investment opportunities. For instance, an airline could use the model to assess potential alliances, comparing candidates on criteria like network expansion potential, brand compatibility, and regulatory alignment. Similarly, carriers could apply this framework to fleet investments or airport infrastructure expansions by evaluating long-term cost efficiencies, environmental impact, and operational capacity. By applying this adaptable, evidence-based model across different decision-making contexts, airlines can make complex choices that align with long-term growth strategies, enhancing competitiveness and operational resilience in an industry marked by constant change.

The study has several limitations, primarily stemming from its reliance on expert judgment, which, despite the application of fuzzy logic adjustments, may still introduce an element of subjectivity into the evaluation process. Expert assessments, while valuable for capturing nuanced insights, can vary based on individual experience or perspective, potentially influencing the final rankings. Additionally, the data sources used in this study, such as economic and tourism metrics, present their own constraints; factors like seasonal fluctuations in tourism or recent shifts in economic indicators may not be fully captured in the static data applied here. Furthermore, while the criteria selected for analysis align with Turkish Airline s' strategic goals, alternative criteria—such as specific environmental impact measures or emerging regulatory factors—could provide additional context and might influence rankings differently if incorporated. These limitations suggest that while the model provides a robust foundation for decision-making, it would benefit from periodic updates and consideration of evolving industry factors to maintain accuracy and relevance.

Future research could enhance the model by integrating dynamic, real-time data, such as passenger flow patterns, seasonal demand fluctuations, and real-time economic indicators, which would allow for more adaptive and responsive decision-making. By incorporating these time-sensitive variables, the model could better capture the transient factors that significantly impact route viability and competitiveness in the airline industry. Additionally, further testing of this model in various decision-making contexts could reveal its versatility and adaptability. For instance, applying the model to evaluate potential airline mergers or strategic partnerships could help assess compatibility across multiple criteria, such as market alignment, regulatory considerations, and operational synergies. Similarly, expanding the model to assess sustainability initiatives, like carbon offset programs or investments in green technology, would allow airlines to balance environmental goals with financial and operational priorities, aligning with the industry's growing emphasis on sustainability. These extensions would not only refine the model's robustness but also provide broader applications across diverse strategic challenges faced by airlines today.

7. Conclusion

The purpose of this study was to develop a robust decision-making framework for airline route selection, with a specific case application for Turkish Airlines, aimed at enabling airlines to strategically evaluate and prioritize potential destinations based on a comprehensive blend of quantitative and qualitative criteria. Through the integration of Entropy weighting and the 2-Tuple Linguistic T-Spherical Fuzzy Decision model, the framework assessed various destinations for Turkish Airlines, ultimately identifying San Antonio (SAT) as the top-ranked option, followed by Portland (PDX) and Nashville (BNA). Key findings revealed that criteria such as market demand and economic impact had the most significant influence on rankings, reflecting their importance in ensuring route profitability and alignment with strategic growth objectives. The framework's ability to handle both objective metrics and subjective expert opinions provides airlines, including Turkish Airlines, with a balanced approach for strategic route planning, offering a scalable, adaptable tool for informed decision-making in the dynamic aviation industry.

This research offers significant practical implications for airline management by providing a structured, data-driven model that enhances strategic route planning and resource allocation. The model's ability to integrate objective data, like economic impact and market demand, with subjective expert insights, such as regulatory feasibility, enables a comprehensive evaluation of potential destinations, leading to more informed and balanced decisions. Its robustness is demonstrated through sensitivity analysis, showing stable results even with varied weightings, which makes the model adaptable to the airline industry's dynamic nature, where market conditions and strategic priorities often shift. By enabling airlines to evaluate destinations based on a mix of quantifiable metrics and nuanced expert assessments, the model provides a resilient framework that supports sustainable growth, optimizes resource investment, and aligns with long-term strategic goals amidst an evolving aviation landscape.

This study contributes specifically to the field of airline destination selection by integrating Entropy weighting with the 2-Tuple Linguistic T-Spherical Fuzzy Decision model, using a comprehensive framework that balances both quantitative metrics and qualitative expert evaluations. Unlike traditional MCDM methods, which often emphasize either objective data or subjective insights, this integrated approach allows for a nuanced handling of diverse data types, making it particularly effective in addressing the multi-dimensional challenges inherent in airline route selection. By applying this cohesive model, the study offers a tailored, adaptable framework that meets the complex demands of strategic decision-making in the aviation sector. This advancement enriches the literature on MCDM applications in aviation and provides a robust tool for airline practitioners to enhance their strategic route planning and expansion efforts.

Future research could build on this model by integrating real-time data, such as passenger flow, economic shifts, and seasonal demand, to create a more dynamic and responsive decision-making tool for the airline industry. Additionally, applying the model in other strategic contexts—such as evaluating mergers, partnerships, or sustainability initiatives—could demonstrate its versatility and effectiveness across diverse decision areas. There is also potential to refine and adapt this model for use in other industries that encounter complex, multi-dimensional decision-making challenges, such as logistics, energy, and finance. These sectors, which similarly weigh both quantitative metrics and qualitative insights, could benefit from a structured, flexible framework that balances hard data with expert assessments, providing a robust foundation for strategic growth and operational efficiency in rapidly changing environments.

This study's model holds significant relevance for the evolving needs of the airline industry, providing a decision-making tool that aligns with the demands for adaptability, resilience, and strategic insight in a highly competitive and rapidly changing market. By effectively integrating quantitative data with qualitative expert judgments, the model offers a balanced framework that enables airlines to make informed and flexible decisions. Its robustness, confirmed through sensitivity testing, ensures that airlines can rely on this model to maintain stability even as market conditions and strategic priorities shift. As airlines increasingly seek growth opportunities in uncertain and dynamic environments, this model provides a valuable foundation for future route planning, resource allocation, and overall strategic decision-making, supporting sustainable, data-driven expansion.

CRediT authorship contribution statement

Filiz Mizrak: Writing – original draft, Visualization, Software, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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