IBN HALDUN UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF AIR TRANSPORT MANAGEMENT

MASTER THESIS

AIRLINE NEW ROUTE SELECTION WITH PYTHAGOREAN FUZZY AHP AND MOORA METHODS: AN APPLICATION FOR AN AIRLINE

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THESIS SUPERVISOR
PROF. ALİ OSMAN KUŞAKCI

ISTANBUL, 2024

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by
MARWAH ATHAB

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science in Air Transport Management

THESIS SUPERVISOR
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APPROVAL PAGE

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Air Transport Management

Thesis Jury Members

Title - Name Surname	Opinion	Signature

This is to confirm that this thesis complies with all the standards set by the School of Graduate Studies of Ibn Haldun University.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Surname: Marwah Athab

Signature:

ÖZ

PİSAGOR BULANIK AHP VE MOORA YÖNTEMLERİ İLE HAVAYOLU YENİ ROTA SEÇİMİ: BİR HAVAYOLU İÇİN UYGULAMA

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Anahtar Kelimeler: Bulanık MOORA Yöntemi, Havacılık Endüstrisi, Pisagor Bulanık AHP, Yeni Rota Seçimi.

ABSTRACT

AIRLINE NEW ROUTE SELECTION WITH PYTHAGOREAN FUZZY AHP AND MOORA METHODS: AN APPLICATION FOR IRAQI AIRWAYS

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The airline industry is fiercely competitive, and choosing new locations is essential to maintaining carriers' competitiveness and financial success. However, because there are so many different variables and requirements to take into account, this procedure is frequently difficult and complex. An effective choice of new routes can result in large benefits and returns, but an inefficient choice can have negative effects. In aiding airline companies in selecting optimal routes and destinations, establishing efficient frameworks and decision-making techniques is crucial. By evaluating and validating the key factors that influence airlines' decision-making processes, this research intends to alleviate the difficulties associated with new route selection in the airline sector. What are the primary factors influencing airlines' choice of new routes? This is the research question that directs this investigation. A two-pronged methodology is used to accomplish the study goal. The first route entails desk research, which includes looking at a number of instances and the literature on the current conceptual framework. This contributes to a thorough grasp of the variables and standards used to choose a new path. The second way emphasizes the employment of a hybrid model that combines the Interval-Valued Pythagorean Fuzzy AHP technique for weighting the chosen criteria and the Fuzzy MOORA method for evaluating and ranking the alternatives. The results of this study show that the main criteria of cost (40% weight) and demand (17% weight) impact route selection decisions more than social and economic conditions (28% weight) and competitiveness (15% weight). This study adds to the body of knowledge in the area of choosing new airline routes and offers useful information to industry decision-makers. Airlines may improve their competitiveness and profitability by tackling the difficulties and uncertainties involved in choosing new routes and by ultimately making more strategic decisions.

Keywords: Aviation Industry, Fuzzy MOORA Method, New Route Selection, Pythagorean Fuzzy AHP.

DEDICATION

It is dedicated to the aviation sector in my country.

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I would like to thank my parents, my husband, and my uncle for their support. Also, I would like to thank my supervisor for his guidance and support.

Marwah Athab

ISTANBUL, 2023

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LIST OF SYMBOLS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
DM	Decision Maker
EDM	Expert Decision Maker
IVPFAHP	Interval-Valued Pythagorean Fuzzy AHP
MOORA	Multi-Objective Optimization on The Basis Of Ratio Analysis
MCDM	Multi-Criteria Decision Making
NOM	Network Optimization Model
RPA	Route Profitability Analysis
SAS	Scandinavian Airlines System
cij	Selection Criterion
D	Difference Matrices
S	Interval Multiplicative Matrices
wi	Weight
T	Weight Matrix
λ	Degree of Hesitation
μ	Degree of Membership
υ	Degree of Non-Membership
τ	Determinacy Value
Σ	Sum Operation

CHAPTER I

INTRODUCTION

Airline route selection is a complex process that involves careful analysis and planning to determine the most profitable routes to add to an airline's network. New route selection is a critical decision for airlines, as it can impact the airline's financial performance, market position, and brand image. (Pal, Belobaba, and Odoni, 2007).

When airlines consider new routes, they must evaluate a range of factors, such as demand, competition, operational costs, airport infrastructure, government regulations, and geopolitical considerations. The airline must also consider the potential risks and benefits associated with adding a new route to its network. One key consideration in new route selection is the potential market demand for the route. Airlines typically conduct market research to determine the size of the potential market and estimate the demand for air travel on the new route. They may also evaluate the competition on the route, including other airlines and alternative modes of transportation, to determine the level of demand for the service (Borger and Abdelghany, 2013).

Operational costs associated with a new route constitute another crucial factor. Airlines must estimate expenses related to flying to and from the destination airport – such as fuel, maintenance, and crew costs. They might also consider the availability and pricing of ground handling services, airport fees, and other operational expenditures (Humphreys and Forsyth, 2015).

Regulatory policies and geopolitical concerns can also affect an airline's decision to implement a new route. Aspects such as airspace limitations, visa prerequisites, and political unrest must be accounted for when assessing new routes (Dresner and Zhu, 2018).

In summary, careful examination and preparation are necessary in choosing new routes so that they prove profitable and sustainable in the long run.

1.1. Research Problem

This problem could involve examining a variety of factors that could impact the success of a new route, such as demand, competition, fuel costs, route distance, and more. It could also involve developing models or algorithms that could help airlines identify the most promising new routes based on these factors, as well as other relevant data.

1.2. Research Objective and Research Question

The main objective of this research is to provide a guiding framework for airlines looking to invest in the establishment of new routes. In pursuit of this objective, the study employs MCDM methods, given the problem's inherent nature. The study's goals can be outlined as follows:

- To identify and review the main criteria that impact airlines' new route selection.
- To validate the effectiveness of the Multi-Criteria Decision Making (MCDM) approach in route selection.
- To apply the Interval-Valued Pythagorean Fuzzy AHP method for weighting the selected criteria.
- To utilize the MOORA method for evaluating and ranking alternative routes.
- To provide recommendations for enhancing the new route selection process in the airline industry.

Consequently, the dilemma faced by airlines brings forth several crucial inquiries:

- What are the main criteria that influence airlines' decisions in selecting new routes?
- How effective is the Multi-Criteria Decision Making (MCDM) approach in the context of route selection?

- How can the Interval-Valued Pythagorean Fuzzy AHP method be applied to weigh the selected criteria?
- How can the MOORA method be used to evaluate and rank alternative routes?
- What recommendations can be provided to improve the new route selection process in the airline industry?

These goals and research questions will direct the study in order to fully comprehend the factors influencing new route selection and assess the efficacy of the suggested methodology. The study intends to advance our understanding of decision-making processes in the aviation sector by meeting these objectives and addressing the research issues.

1.3. Research Novelty

The innovative aspect of the model presented in this research lies in employing a hybrid MCDM approach, which fuses the Interval-valued Pythagorean Fuzzy AHP and MOORA techniques. Furthermore, no previous studies attempted to use the Interval-valued Pythagorean Fuzzy AHP combined with Interval-valued Pythagorean Fuzzy MOORA to address the route selection issue.

1.4. Research Structure

This research focuses on the implementation of a combined MCDM model designed to address new airline route selection issues and is composed of five sections.

The first chapter introduces the study, defines the research problem, outlines the study's objectives and research queries, and highlights the innovative elements of the proposed study.

Chapter two offers an extensive literature survey regarding new airline route selection topics. The chapter covers the evolution of methods and techniques for selecting new routes, a review of the concepts and models developed, a comparative analysis of the techniques and methods, and selection criteria for assessing a new route.

The third chapter presents the study's suggested approach and how it was applied in an all-inclusive network airline in Iraq. The initial section outlines the fundamental ideas of the fuzzy technique, as well as the procedures for Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) and Interval-valued Pythagorean Fuzzy AHP. Following this, the use of this combination strategy is further clarified by means of a pairwise comparison of the route selection criteria and an evaluation of three alternatives in relation to these criteria. In Chapter Four, the findings from this hybrid methodology are the main focus. The results of the Interval-valued Pythagorean Fuzzy AHP employed here demonstrate the importance and influence of the chosen criteria on route selection. Additionally, the results of Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) determine which of the three other routes is the best choice.

In conclusion, the fifth chapter brings the study to a close while also examining the research's contributions to existing literature and acknowledging its limitations. Furthermore, recommendations for future exploration of the topic are provided.

CHAPTER II

LITERATURE REVIEW

2.1. Evolution of Methods and Techniques for Selecting New Routes

According to Pineda et al (2018), over time, there have been substantial improvements in procedures and approaches for choosing new routes in the airline business. Initially, expert judgment and qualitative evaluations played a significant role in the route selection process. Airlines have, however, shifted toward more quantitative and data-driven strategies as a result of the development of more sophisticated analytical tools and improvements in data accessibility. The application of statistical models and econometric methodologies is a noteworthy development in the discipline. Regression analysis, for instance, has been used to pinpoint the major variables affecting route profitability, such as passenger demand, rivalry, and operational expenses (Putra & Kusumastuti, 2018). Airlines can choose routes with confidence by looking at past data and taking into account different economic and market factors. The use of network analysis and optimization models is another new development. These strategies strive to maximize the overall network efficiency and profitability while taking into account the interconnectedness of routes within an airline's network. Airlines can evaluate the potential effects of adding additional routes on the overall network performance using network-based models, such as the Hub Location Problem and the Airline Network Design Problem (Soylu & Katip, 2019).

2.2. Review of the Concepts and Models Developed

In the airline business, a number of concepts and models have been created to address the difficulties involved with new route selection. The Route Profitability Analysis (RPA), which concentrates on determining the financial viability of potential routes, is one well-known concept. To calculate the viability of new routes, RPA takes into account a variety of cost and revenue elements, including fuel costs, airport fees, passenger demand, and ticket prices (Ng et al., 2021). In order to improve route selection choices, mathematical programming models have also been developed. These models take into account a variety of goals, including increasing passenger demand, reducing expenses, and balancing route connectivity. Airlines can identify the ideal set of routes that fit with their strategic objectives by modeling the route selection problem as a mathematical optimization model (Ansari et al., 2018). Furthermore, the route-selection process has been transformed by the development of data-driven methodologies such as machine learning and predictive analytics. These algorithms are capable of finding patterns, forecasting passenger demand, and determining the profitability of routes by analyzing enormous amounts of historical data. Airlines, for instance, can forecast future passenger demand using machine learning algorithms based on demographics, economic data, and travel habits (Hou et al., 2020).

2.3. Comparative Analysis of the Techniques and Methods

According to Castiglioni et al (2018), the various strategies utilized in the sector can be better understood by comparing the processes and procedures used by airline firms while choosing new routes. This evaluation assists in determining the benefits, drawbacks, and ideal procedures related to various approaches. These strategies are illustrated and shown to be effective in several real-world case studies. The Route Prospective Analysis (RPA), which evaluates the prospective demand and profitability of new routes, is a frequently used technique. For instance, the RPA model was utilized in a case study by Emirates Airlines to assess the feasibility of launching a new route between Dubai and Panama City (Urban, 2018). Emirates Airlines was able to analyze the route's potential profitability and make well-informed judgments about its debut because the RPA model's analysis of aspects like passenger demand, competition, and market dynamics.

The Network Optimization Model (NOM), which takes into account the total network efficiency and profitability, is another technique utilized by airline firms. The NOM model was used in a case study by Southwest Airlines to optimize the airline's network and find prospective additional routes (Goyan, 2023). The NOM model assisted Southwest Airlines in identifying high-demand routes and improving network performance by looking at elements like passenger flows, operational expenses, and route connections. Additionally, some airline corporations choose routes using advanced analytics and machine learning approaches. For instance, machine learning algorithms were used in a case study by Air Asia to examine historical passenger data, market trends, and customer preferences (Le & Rajah, n.d.). By utilizing these algorithms, Air Asia was able to spot trends and forecast demand for prospective new routes, allowing them to choose their routes based on data. The comparison of these methods demonstrates the variety of methods used by airline corporations to choose new routes. The NOM model emphasizes network optimization, the RPA model places a strong emphasis on financial sustainability, and the data-driven method makes use of advanced analytics (Hofer, 2022). Each approach has particular benefits and factors to take into account, and the success of each depends on the goals, resources, and market circumstances of the individual airline. It is clear from examining these real case studies and contrasting the results of various methodologies that a combination of strategies catered to the unique circumstances of the airline can produce the best effects. The network structure of the airline, market characteristics, data that is readily available, and decision-making preferences should all be taken into account when choosing the best technique.

2.4. Application of AHP and MOORA

The literature has paid a lot of attention to the use of the Pythagorean Fuzzy Analytic Hierarchy Process (AHP) and Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) approaches in complex decision-making (Wu et al., 2022). In order to address the complexities and uncertainties associated with decision-making processes, such as the choice of new routes in the airline sector, these methodologies provide a systematic and structured approach. To address uncertainty and imprecision in decision-making, Pythagorean Fuzzy AHP is an extension of the conventional AHP approach (Karasan et al., 2019). This approach enables decision-makers to represent their conclusions as linguistic variables or fuzzy numbers, accounting for the subjectivity and ambiguity frequently present in real-world decision-making situations. Pythagorean Fuzzy AHP permits the determination of appropriate weights for the criteria, which are crucial for decision-making, by taking into account various criteria and their relative relevance. Using Pythagorean Fuzzy AHP in combination with MOORA offers a strong foundation for multi-objective decision-making (Sasikumar & Sivasangari, 2022). A multi-criteria decision-making technique called MOORA evaluates and ranks alternatives depending on how well they perform against a variety of criteria. The integrated method enables decision-makers to take into account trade-offs between several objectives and make well-informed decisions by using Pythagorean Fuzzy AHP to weigh the criteria and MOORA for alternative evaluation (Yucesan & Gul, 2020).

In the context of choosing new routes for airlines, Pythagorean Fuzzy AHP and MOORA's propensity to handle complex decision-making circumstances is particularly pertinent. Numerous factors, including market demand, profitability, rivalry, operational costs, and strategic fit, are taken into consideration during the selection process. In addition, these factors frequently interact and clash with one another, making decision-making difficult. Pythagorean Fuzzy AHP's fuzzy character allows for the subjectivity and uncertainty involved in decision-making (Kaya et al., 2022). Given the verbal concepts and hazy numbers that represent their opinions, decision-makers are able to convey their preferences in a more flexible and realistic way. When dealing with subjective criteria or when there is little accurate information available, this feature is very important. Additionally, by taking into account many objectives at once, the integration of MOORA with Pythagorean Fuzzy AHP offers a thorough examination of solutions. By comparing the performance of each alternative to the weighted criteria, decision-makers may determine which solutions best meet their goals.

According to Deveci et al. (2021), the use of Pythagorean Fuzzy AHP and MOORA methodologies in the airline industry for the selection of new routes offers a solid strategy for handling the complexities and uncertainties associated with decision-making. These techniques offer a methodical framework for examining criteria, deciding their relative weight, and gauging the effectiveness of alternatives. Pythagorean Fuzzy AHP and MOORA contribute to the efficient and well-informed decision-making process in the context of aircraft route selection by incorporating fuzzy logic and multi-objective analysis.

2.5. Identification of Key Trends and Advancements

Recent years have seen a number of significant changes and breakthroughs in the field of airline route selection, driven by developments in technology, the accessibility of data, and changing market dynamics. The decision-making process for choosing new routes in the airline sector has been considerably influenced by these trends and developments. The following significant developments and trends can be determined using the case studies and supplementary examples provided:

- Data-driven Methods: Making decisions based on data Airlines can now choose routes using data-driven methods because of the availability of enormous volumes of data and improvements in analytics tools. Airlines can decide on the viability and profitability of a route based on historical data, market trends, and customer preferences (Grandhi et al., 2021). To examine aspects like passenger demand, market rivalry, and operational costs, for instance, airlines like Delta Air Lines have put in place advanced data analytics systems (Vinod, 2021). These data-driven strategies improve the precision and potency of route selection choices.
- Network Optimization: In order to improve efficiency and profitability, airlines are putting more and more effort into fine-tuning their route networks. Airlines can find chances for network growth and route optimization by taking into account variables, including hub connections, route density, and traffic flows. To find prospective new routes and improve its current network, British Airways, for instance, has used network optimization tools (Belias et al 2021). This pattern highlights how crucial comprehensive network planning is when choosing a route.
- Analysis of Market Demand: Choosing workable routes requires an understanding of market demand. Airlines are utilizing cutting-edge market analysis tools to estimate passenger demand and identify potential development markets. For instance, Ryan Air employs tools for market analysis to determine underserved routes, examine market saturation, and assess the possibility of profitable routes (Knorr, 2019). Airlines can target profitable markets and choose the best routes by researching variables, including demography, economic indicators, and travel trends.
- Sustainable Route Considerations: With an increased focus on environmental awareness and sustainability, airlines are increasingly taking the environmental

impact of their routes into account. When choosing a route, they consider elements like fuel economy, carbon emissions, and noise pollution. For instance, the Scandinavian Airlines System (SAS) has put in place a sustainability plan that involves evaluating the effects of new routes on the environment (Wright, 2019). The industry's dedication to implementing ecologically friendly procedures in route selection is shown in this development.

- Technological Developments: The process of choosing a route has been completely transformed by technological developments such as aviation software and route planning tools. These tools give airlines the ability to simulate different situations, evaluate complex data, and improve routes based on a variety of factors. Airlines like Lufthansa, for instance, use cutting-edge route planning software to assess variables, including flight duration, operating expenses, and airport infrastructure (Wendt et al., 2020). The effectiveness and precision of route selection judgments are improved by these technical developments.

Data-driven decision-making, network optimization, market demand analysis, sustainable route considerations, and technical breakthroughs are the major trends and developments in the field of airline route selection. Airlines can choose new routes more intelligently and strategically by embracing these trends and utilizing technological improvements, which will ultimately increase their competitiveness and profitability in the dynamic aviation sector.

2.6. Selection Criteria for Evaluating a New Route

In accordance with the findings from the literature review, a number of carefully chosen criteria, shown in Fig. 2.1, include:

- Market Demand: According to Kitsou et al.'s (2022) examination of passenger traffic data, each destination's yearly passenger counts and growth rates were taken into account.
- Economic Viability: To assess the potential profitability of running routes to these locations, economic metrics like GDP and disposable income were taken into account (Dwyer, 2022).

- Competition: The level of competition was evaluated by examining market share and the existence of significant airlines flying to these locations (Lai et al., 2022).
- Tourism Potential: Each destination's tourism potential was evaluated by taking into account elements, including the number of tourist attractions, cultural heritage sites, and hotel rooms (Jover & Diaz-Parra, 2022).

The primary evaluation criteria can be denoted as C_i, with 'i' representing the count of pertinent primary criteria. Additionally, secondary criteria can be expressed as C_{ij}, where 'j' signifies the number of subordinate criteria corresponding to the ith primary criterion.

C1, Social / Economic Conditions: The destination region's social and economic conditions play a crucial role in determining our selection process.

C11, City Population: The sub-criterion serves as a fascinating social aspect when forging new routes. Analyzing catchment zones will unveil the anticipated demand, unraveling a world of possibilities.

C12, Income (GDP): Income and GDP epitomize the destination city's purchasing power, serving as a gauge for the county's economic expansion.

C13, Tourism Potential: A destination's attractiveness to airlines and passengers is affected by its significant tourism potential.

C2, Cost: The overall cost of the route encompasses various expenditures, including fuel, crew, airport charges, maintenance, handling, and other associated costs.

C21, Distance*Fuel: Route distance relates to fuel consumption, which largely impacts cost.

C22, Route Cost: Besides fuel, airport fees, maintenance, and personnel costs significantly affect a route's profit.

C3, Demand: Primary criteria reflect overall passenger demand for a destination.

C31, Number of Passengers: the number of passengers carried by airline passengers on direct flights from origin to destination

C32, Frequency: the number of daily and weekly flights operated by airlines on this route.

C4, Competitiveness: This factor reveals competitor presence on the same route.

C41, Price (Fare): This sub-criterion represents the average ticket rates for competitors operating routes.

C42, Number of Competitors: The count of airlines on this itinerary.

C43, Frequency of Competitors: This criterion shows the number of daily and weekly flights operated by competing airlines on this itinerary.

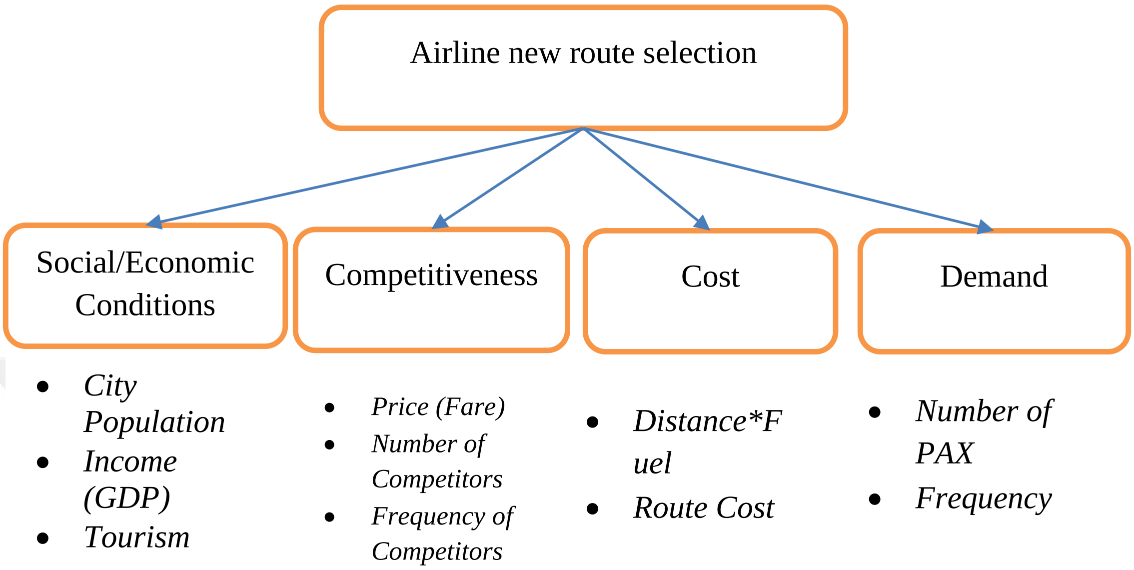

Figure 2.1. Criteria Used for Route Selection

CHAPTER III

METHODOLOGY

Our framework, as shown in Figure 3.1, integrates the Fuzzy Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) and Fuzzy Analytic Hierarchy Process (Fuzzy AHP) techniques. We can handle imprecision, uncertainty, and many criteria in decision-making processes successfully by combining these two approaches. The methodological framework includes a number of crucial elements. First, we apply the theory of fuzzy sets to describe and manage imperfect and ambiguous information (Garg, 2018). An adaptable and reliable method for capturing and controlling ambiguity and vagueness in decision-making situations is provided by fuzzy sets. Next, we add intuitionistic fuzzy sets to the fuzzy sets theory. We may represent the degree of membership as well as the degree of non-membership and reluctance in decision-making using intuitionistic fuzzy sets. With this extension, uncertainty is better represented, and assessments are more precise. We offer Pythagorean fuzzy sets to deal with decision problems involving preference and uncertainty. We are able to model both crisp and fuzzy preferences using Pythagorean fuzzy sets. Decision-makers can communicate their preferences more fully and precisely with the help of this representation.

We combine the Fuzzy MOORA method and the Interval-Valued Pythagorean Fuzzy AHP (IVPFAHP) method within the methodological framework. In order to create a more thorough and practical framework for making decisions, the IVPFAHP technique integrates fuzzy sets, intuitionistic fuzzy sets, and Pythagorean fuzzy sets into the Analytic Hierarchy Process (AHP). For each criterion, fuzzy weights are derived, pairwise comparisons are performed, linguistic assessments are performed, and fuzzy weights are aggregated to produce an overall priority vector. The MOORA method, on the other hand, is a multi-objective optimization strategy that evaluates alternatives according to how well they perform against a variety of criteria. It takes into account normalizing linguistic evaluations, weighing evaluations, calculating fuzzy synthetic utility values, and ranking options in the end. We can handle unclear assessments, various criteria, and imprecise evaluations in decision-making processes by combining these strategies. In the sections that follow, we shall examine the specific procedures and uses of the IVPFAHP and Fuzzy MOORA approaches in the context of choosing airline routes.

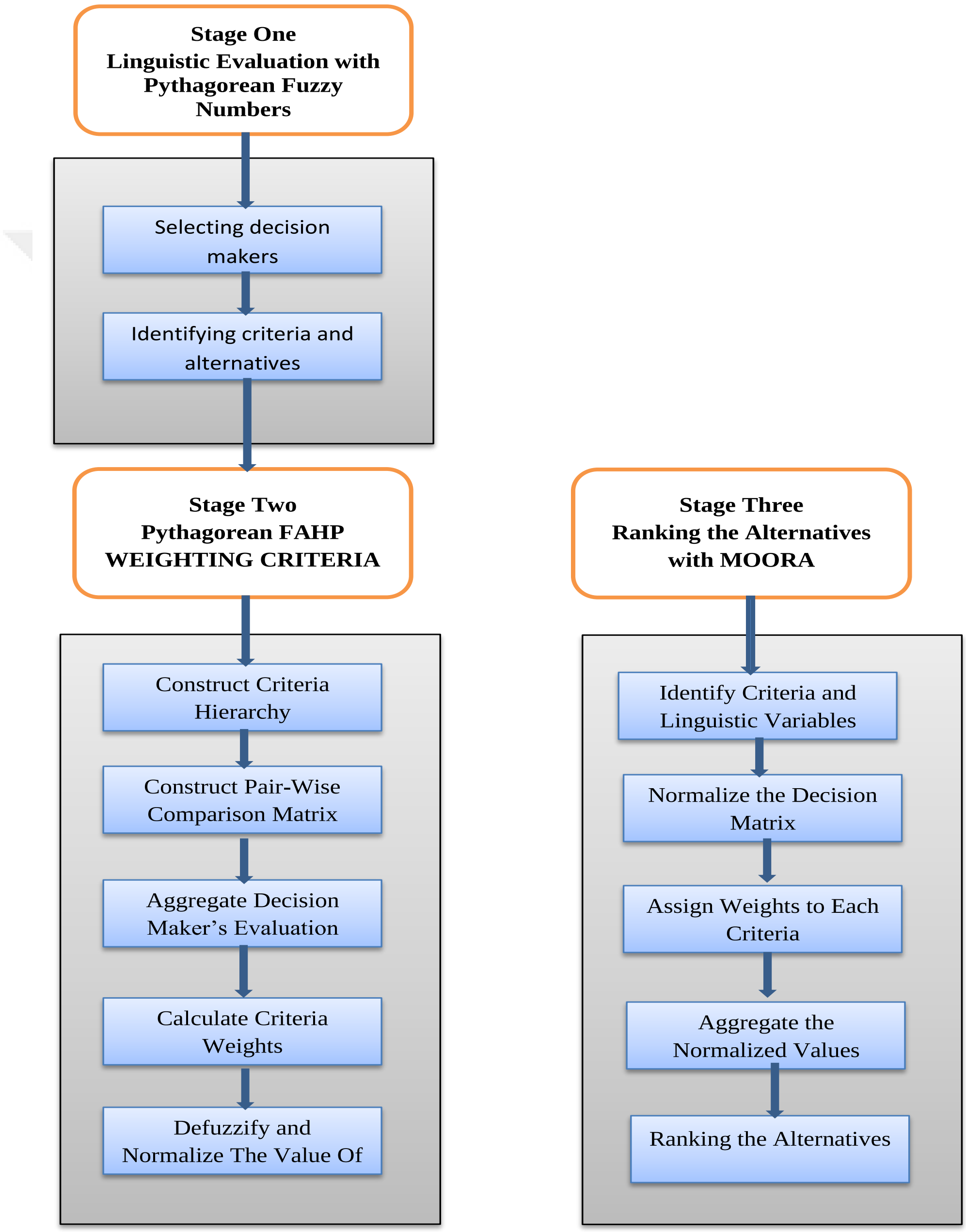

Figure 3.1. Proposed Methodology

3.1. Fuzzy Sets

A mathematical foundation for managing uncertainty and imprecision in the decision-making process is provided by fuzzy sets. Fuzzy sets permit partial membership in contrast to conventional binary sets, which categorize entries as fully belonging to a set or not. By giving items varying degrees of membership dependent on how related or pertinent they are to the set, they make it possible to convey hazy and unclear information. A membership function that maps each element to a value between 0 and 1 indicating the degree of membership, serves as the definition of fuzzy sets (Zadeh, 2021). Depending on the exact issue at hand and how membership is perceived, the membership function's shape may change. Triangular, trapezoidal, and Gaussian shapes are typical membership functions. Numerous mathematical operations are supported by fuzzy sets, making it easier to manipulate and analyze them. These operations include complement, difference, intersection, and union. Let's consider two fuzzy sets, A and B. Various mathematical operations can be applied to fuzzy sets, including complement, difference, intersection, and union.

Union (max operator): The union of two fuzzy sets A and B are obtained by assigning the maximum membership value at each point. It represents the total membership of both sets. Mathematically, the union is defined as:
$A \cup B = \max(A(x), B(x))$, for all x

Intersection (min operator): The intersection of two fuzzy sets, A and B, identifies the shared membership between the sets. It is obtained by assigning the lowest membership value at each point. Mathematically, the intersection is defined as:

$A \cap B = \min(A(x), B(x))$, for all x

These operations allow for the manipulation and analysis of fuzzy sets, providing a framework for managing uncertainty and imprecision in the decision-making process. The maximum membership value is assigned to each point in the union of the two fuzzy sets, A and B, producing a fuzzy set that represents the total membership of both sets. Assigning the lowest membership value at each point, the intersection, on the other hand, identifies the shared membership between the sets.

The items that do not belong to a fuzzy set are represented by the degree of non-membership, which is calculated by the complement operation. We get it by taking the membership function away from one. Mathematically, the complement operation is defined as:

$A' = 1 - A(x)$, for all x

The relative complement, also referred to as the difference operation, captures the membership of one set while excluding that of another set (Mittal et al., 2020). It is obtained by taking the minimum of the membership value of the first set and the complement of the second set. Mathematically, the relative complement is defined as:

$A - B = \min (A(x), 1 - B(x))$, for all x

Numerous characteristics of fuzzy sets contribute to their effectiveness in decision-making. According to the extensionality principle, two fuzzy sets are equivalent if their membership functions are the same. According to the principle of identity, the original set is produced when a fuzzy set intersects with itself. According to the principle of impotence, the original set results from the union of a fuzzy set and itself (Singh et al., 2020). These characteristics provide coherent and consistent fuzzy set operations. Additionally, fuzzy sets support the idea of graded membership, in which items may be members to varied degrees. Because of this flexibility, decision-makers can record and analyze complicated real-world scenarios and convey imprecise and ambiguous information. Fuzzy sets permit partial membership in contrast to conventional binary sets, which categorize entries as fully belonging to a set or not. By giving items varying degrees of membership dependent on how related or pertinent they are to the set, they make it possible to convey hazy and unclear information.

A membership function (x) that converts each element x to a value between 0 and 1 indicating the degree of membership, is what defines fuzzy sets. Depending on the exact issue at hand and how membership is perceived, the membership function's shape may change. Triangular, trapezoidal, and Gaussian shapes are typical membership functions. Numerous mathematical operations are supported by fuzzy sets, making it easier to manipulate and analyze them. According to Singh et al. (2020), these operations include union (A B), intersection (A B), complement (A'), and difference (A - B).

The largest membership value at each location is used to calculate the union of two fuzzy sets, A and B, producing a fuzzy set that represents the combined membership of both sets:

$$(A \cup B)(x) = \max(\mu A(x), \mu B(x))$$

The intersection assigns the minimum membership value at each respective point to discover the shared membership among sets.

$$(A \cap B)(x) = \min(\mu A(x), \mu B(x))$$

The items that do not belong to a fuzzy set are represented by the degree of non-membership, which is calculated by the complement operation. By deducting the membership function from one, it can be found:

$$(A')(x) = 1 - \mu A(x)$$

The relative complement, commonly referred to as the difference operation, captures the membership of one set while excluding that of another set:

$$(A - B)(x) = \max(\mu A(x) - \mu B(x), 0)$$

These characteristics make fuzzy set operations consistent and coherent (Singh et al., 2020). Additionally, fuzzy sets support the idea of graded membership, in which items may be members to varied degrees. This statistical approach enables decision-makers to capture and analyze complex real-world events by representing ambiguous and unclear information.

3.2. Pythagorean Fuzzy Sets

Pythagorean fuzzy sets expand on the idea of fuzzy sets by adding extra factors that accurately depict the ambiguity and uncertainty present in decision-making processes. Give a more adaptable framework for representing and managing uncertain information, which was first introduced by Pythagorean fuzzy sets (Garg, 2018). The degree of membership (μ), the degree of non-membership (υ), and the degree of hesitation (λ) are the defining properties of Pythagorean fuzzy sets. Their three distinguishing traits are the degree of membership, the degree of non-membership, and the degree of reluctance. Similar to conventional fuzzy sets, the membership degree denotes the degree of membership of an element to the set. It can be mathematically represented as μ(x) = f(x), where f(x) is a membership function that assigns a degree of membership to the element x. The non-membership degree υ calculates how far an element deviates from the set. It can be expressed as:

$$\nu(x) = 1 - \mu(x)$$

The level of uncertainty or doubt used to determine the membership and non-membership degrees is reflected in the hesitancy degree. A potent tool for describing and quantifying uncertainty in decision-making is the use of Pythagorean fuzzy sets. Language-based phrases, numerical numbers, or interval ranges can all be used to convey the membership degree, non-membership degree, and hesitation degree. The hesitation degree can be denoted as λ(x) = g(x), where g(x) is a function that captures the hesitation associated with the element x. By using triangle membership functions, Pythagorean fuzzy sets are frequently represented. The triangle membership function captures the intermediate degrees of membership and enables a smooth transition from full membership to full non-membership. Depending on the unique issue and the facts at hand, the membership function's shape can be changed.

A Pythagorean fuzzy set A is denoted mathematically by the formula

$$A = \{\langle X, \mu_A(X), \vartheta_A(X)\rangle x \in X\}$$

Where X is the element, μ_A denotes the membership degree, ϑ_A denotes the non-membership degree (Garg, 2018). These variables together describe the ambiguity and uncertainty around the element's membership in the set. Pythagorean fuzzy sets' portrayal of uncertainty enables decision-makers to take in more complicated and nuanced data. They are able to communicate their level of membership as well as their level of non-participation and their amount of reluctance to award these degrees. By taking into account numerous dimensions of uncertainty, this more comprehensive depiction enables more accurate and thorough decision-making.

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μ (x) = f(x)

Where μ (x) represents the membership degree of the element x, and f(x) is a membership function that assigns a degree of membership to the element.

The degree to which an element does not belong to the set is quantified by the non-membership degree. It can be calculated using the formula:

ϑ (x) = 1 - μ (x)

where ϑ (x) represents the non-membership degree of the element x.

The level of uncertainty or doubt used to determine the membership and non-membership degrees is reflected in the hesitation degree. The hesitation degree can be denoted as:

$\lambda(x) = g(x)$

Where λ(x) represents the hesitation degree of the element x, and g(x) is a function that captures the hesitation associated with the element.

A potent tool for describing and quantifying uncertainty in decision-making is the use of Pythagorean fuzzy sets. Language-based phrases, numerical numbers, or interval ranges can all be used to convey the membership degree, non-membership degree, and hesitation degree.

By using triangle membership functions, Pythagorean fuzzy sets are frequently represented. The triangle membership function captures the intermediate degrees of membership and enables a smooth transition from full membership to full non-membership (Garg, 2018). Depending on the unique issue and the facts at hand, the membership function's shape can be changed. A Pythagorean fuzzy set A is denoted mathematically by the formula:

$A = (x, \mu(x), \vartheta(x), \lambda(x)),$

- x represents the element in consideration,
- μ (x) denotes the membership degree of the element x,
- ϑ(x) represents the non-membership degree of the element x, and
- λ(x) reflects the hesitation degree associated with the element x.

These variables together describe the ambiguity and uncertainty around the element's membership in the set. Pythagorean fuzzy sets' portrayal of uncertainty enables decision-makers to take in more complicated and nuanced data. They are able to communicate their level of membership as well as their level of non-participation and their amount of reluctance to award these degrees. By taking into account numerous dimensions of uncertainty, this more comprehensive depiction enables more accurate and thorough decision-making.

3.3. Interval-Valued Pythagorean Fuzzy AHP (IVPFAHP) Method

In order to accommodate uncertainty and ambiguity in decision-making, the Interval-Valued Pythagorean Fuzzy AHP (IVPFAHP) method extends the Analytic Hierarchy Process (AHP) by utilizing Interval-Valued Pythagorean Fuzzy Sets.

Table 3.1. Linguistic Scale for IVPFAHP Terms (Karasan et al., 2019)

Linguistic Terms	PFN equivalents IVP numbers			
Certainly Low Importance- CLI	The Lower value of membership degree μ_L	The Upper value of membership degree μ_U	The Lower value of non-membership degree ν_L	The Upper value of non-membership degree ν_L
Certainly Low Importance- CLI	0	0	0.9	1
Very Low Importance - VLI	0.1	0.2	0.8	0.9
Low Importance -VI	0.2	0.35	0.65	0.8
Below Average Importance -BAI	0.35	0.45	0.55	0.65
Average Importance - AI	0.45	0.55	0.45	0.55
Above Average Importance -AAI	0.55	0.65	0.35	0.45
High Importance -HI	0.65	0.8	0.2	0.35
Very High Importance –VHI	0.8	0.9	0.1	0.2
Certainly High Importance –CHI	0.9	1	0	0
Exactly Equal- EE	0.1965	0.1965	0.1965	0.1965

Decision-makers can use the IVPFAHP approach to create decisions that are more reliable and accurate by taking into account various criteria and their linguistic assessments. After expert selection and criteria identification, the criteria's significance is determined. The outlines of the Interval-valued Pythagorean Fuzzy AHP steps are:

1. Pairwise comparison matrices for main and sub-criteria are formed using decision makers' linguistic evaluations and Table 3.1. scale.

2. Difference matrices $\boldsymbol{D} = [d_{ik}]_{m*m}$ is calculated by finding the difference between lower and upper membership/non-membership function values.

$$d_{iKL} = \mu_{iKL}^2 - \nu_{iUK}^2$$
(3.1)

$$d_{iKU} = \mu_{iKU}^2 - \nu_{iUL}^2$$
(3.2)

3. Interval multiplicative matrices *S= (sik)mxm* is computed with these equations.

$$S_{ikL} = \sqrt{1000^{dL}}$$
(3.3)

$$S_{ikU=\sqrt{1000^{dU}}}$$
(3.4)

Determinacy value $\tau = [\tau_{ik}]_{m*m}$ is found using specific equations.

$$\tau_{iK} = 1 - \left(\mu_{ikU}^2 - \mu_{ikL}^2\right) - \left(v_{ikU}^2 - v_{ikL}^2\right)$$
(3.5)

4. Determine the matrix of weights $S = (s_{ik})_{m*m}$ by multiplying the determinacy degrees with $T=(t_{ik})_{m*m}$ matrix, and then normalize using the equations provided.

$$t_{ik} = \left(\frac{S_{ikL}+S_{ikU}}{2}\right)\tau_{ik}$$
(3.6)

5. Normalized priority weights w_i is calculated via specific formulas.

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}}$$
(3.7)

3.4. MOORA Method

The decision-making process becomes more complicated when we face a scenario of multiple objectives with multiple alternatives. In normal situations, the optimization process may lead to reaching satisfactory decisions instead of optimal ones.

This is why researchers such as Roy (1986) presented a pattern for solving Multiple Criteria Decision-Making (MCDM) problems. He suggested four steps to apply the pattern: i) choosing a problem. - choosing the best alternative, ii) sorting the problem - classifying alternatives into relatively homogenous groups, iii) ranking the problem - ranking alternatives from best to worst, and finally, iv) describing the problem - describing the alternatives in terms of their peculiarities and features.

This pattern was extended by researchers such as Bilton and Stuart (2002), who defined three broad categories of MCDM methods: i) the value measurement, ii) the goal, aspiration, and reference level model, and iii) outranking models.

In this study, it was first agreed to use one of the newly developed MCDM methods called MOORA (Multi-Objective Optimization by Ratio Analysis). The MOORA method was first introduced by Brauers and Zavadskas in 2006. It was then further developed by the same research to produce MULTIMOORA, which combines MOORA with multiplicative form. Then, it was decided to apply the Fuzzy MULTIMOORA for Linguistic Reasoning under group decision-making developed by Brauers et al. (2011), which relies on the fuzzy number theory in applying the MULTIMOORA method.

3.4.1. Procedures for the MOORA Analysis

The MOORA method is a matrix-based approach, matrix x_{ij} where its elements x_{ij} denote *i*th alternative of the *j*th objective *(i = 1, 2,...,m and j = 1, 2,...,n),* which consists of two parts: the ratio system and the reference point approach. It involves weighting, normalization, and voting on the significance of objectives. The method treats all objectives equally important, but stakeholders can give more importance to an objective by multiplying the dimensionless number or splitting it into sub-objectives.

The Ratio System of MOORA is a method for internal data normalization, comparing an objective's alternative to all its values of that objective:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \tag{3.8}$$

Where x_{ij}^{*} denotes *i*th alternative of the *j*th objective after internal normalization, typically within the interval [-1; 1].

They are added for a maximum *(j = 1, 2,...,g*) or subtracted for a minimum (*j = g + 1,...,n):*

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^*$$
(3.9)

Where the internal normalized assessment of alternative *i* in relation to all objectives is indicated by the notation alternative y_i^*. Ultimately, the y_i^* are ranked in descending order.

The Ratio System's ratios serve as the basis for the reference point used by the performance management strategy MOORA. The Maximal Objective Reference Point, which is ranked in descending order, is the definition of the reference point. The reference point is selected from among the potential options in a practical and objective manner. The Maximal Objective Reference Point R_m (100; 100) will be the outcome of the choices A (10; 100), B (100; 20), and C (50; 50). Alternative names for the reference point include aspiration objective reference and utopian objective reference. An Aspiration Objective Vector's *qi* coordinates are created as follows: $q_j \leq r_j$; with $(r_j - q_j)$ is the subjective component.

The Aspiration Objective Vector moderates aspirations by choosing smaller coordinates, while the Utopian Objective Vector gives higher values to the reference point's coordinates. This method is useful for Performance Management, student evaluation, and private or public sector performance. The Maximal Objective Vector is self-evident in projects, but it may not be satisfied if stakeholders are satisfied. The Utopian Objective Vector offers a better response to Multi-Objective Optimization, but a filter can be placed beforehand.

3.5. Application of Proposed Method to Airline Route Selection Problem

3.5.1. Selecting Criteria and Alternative Routes

During the initial phase, selection criteria and alternative routes are identified, along with the selection of expert decision-makers (DM) from a full-service airline located in West Asia (Middle East) with a fleet size approaching approximately 40 aircraft that operates as a comprehensive air travel provider connecting both domestic and international destinations. These experts hold a minimum of four years of experience. Six DMs form the first expert group, which assesses the weighting values of criteria, which are defined in Table 3.2, using a questionnaire in Appendix A Table A.1. The first expert group also helps identify five alternative routes. Subsequently, another set of six DMs (from EDM1 to EDM6) evaluates these routes based on selection criteria.

Table 3.2. Evaluation Criteria and Descriptions

Criteria	Definition
C1, Social /Economic Conditions	The destination region's social and economic conditions play a crucial role in determining our selection process.
C11, City *Population*	The sub-criterion serves as a fascinating social aspect when forging new routes. Analyzing catchment zones will unveil the anticipated demand, unraveling a world of possibilities.
C12, Income (GDP) and Trade	Income and GDP epitomize the destination city's purchasing power, serving as a gauge for the county's economic expansion.
C13, Tourism Potential	A destination's attractiveness to airlines and passengers is affected by its significant tourism potential.
C2, Cost	The overall cost of the route encompasses various expenditures, including fuel, crew, airport charges, maintenance, handling, and other associated costs.
*C21, Distance*Fuel*	Route distance relates to fuel consumption, which largely impacts cost.
C22, Route Cost	Besides fuel, airport fees, maintenance, and personnel costs significantly affect a route's profit.
C3, Demand	Primary criteria reflect overall passenger demand for a destination.
C31, Number of Passengers	The number of passengers carried by airline passengers on direct flights from origin to destination.
C32, Frequency	The number of daily and weekly flights operated by airlines on this route.
C41, Price (Fare)	This sub-criterion represents the average ticket rates for competitors operating routes.
C42, Number of Competitors	The count of airlines on this itinerary.
C43, Frequency of Competitors	This criterion shows the number of daily and weekly flights operated by competing airlines on this itinerary.

Three alternative routes were selected with the help of the first group of the (DMs); the alternatives are:

- **City 1**: A city located in the Middle East with a population of about 1,500,000. The main airport in the city serving the area is located about 31 km northwest of the city. According to the General Authority for Civil Aviation (GACA), The Airport handled 10,040,974 passengers in 2022. This represents an increase of 22.6% from 2021. The airport is expected to handle 12 million passengers in 2023 and, it is served by 37 airlines offering domestic and international flights.

- **City2:** A city located in Southeast Asia. The city's main airport is one of the busiest airports in Asia, handling over 58 million passengers in 2019. The airport is expected to continue to grow in the coming years, with passenger traffic projected to reach 100 million by 2030. There are over 80 airlines operating at the airport, handling hundreds of direct and connecting flights to hundreds of destinations around the world. The list includes many major airlines from East and Southeast Asia.

- **City3**: A city located in southwestern Asia with a high potential for tourism. The passenger potential for the international airport is projected to reach 20 million passengers annually by 2025, a significant increase from the current 5 million passengers per year. As of 2023, over 40 airlines will operate flights to the airport, offering both domestic and international connections.

3.5.2. IVPFAHP Method

We applied IVPFAHP to determine the relative importance of evaluation criteria.

The first step in the IVPFAHP approach is to identify the criteria and sub-criteria that are pertinent to the current decision problem. The various elements or considerations that must be made in the decision-making process are represented by the criteria listed in Table 3.2. Experts undertake language analyses and pairwise comparisons, which are conducted using the questionnaire shown in Appendix A, after identifying the criteria. On the links between the criteria, experts offer their evaluations and opinions while expressing their preferences in linguistic terms. The pairwise comparisons and linguistic evaluations are combined to create the fuzzy weights for each criterion. The relative weight or significance of each criterion in the decision-making process is represented by fuzzy weights. Decision-makers can capture the ambiguities and imprecisions inherent in their judgments by combining linguistic evaluations and pairwise comparisons. The overall priority vector for the IVPFAHP analysis is created by combining the fuzzy weights. In this step, the relative weights assigned to each criterion based on pairwise comparisons and linguistic analyses are taken into consideration, as well as the fuzzy weights for each criterion (Baleentis et al., 2012). Before constructing an overall priority vector that demonstrates the relative importance of each criterion in the decision-making process, the aggregation procedure takes into account the relative value of each criterion.

Second step: Using Equations 3.1 and 3.2, difference matrices (D) are computed. Table 3.3. Shows the main criteria's difference matrix, while Table 3.4. displays the social/economic conditions sub-criteria matrix.

Table 3.3. Difference Matrix of Main Criteria

	dL	du	dL	du	dL	du	dL	du
Social /Economic Conditions	0.000	0.000	0.308	0.442	0.123	0.326	-0.264	-0.060
Cost	-0.442	-0.308	0.000	0.000	0.499	0.733	-0.058	0.182
Demand	-0.326	-0.123	-0.733	-0.499	0.000	0.000	0.200	0.450
Competitiveness	0.060	0.264	-0.182	0.058	-0.450	-0.200	0.000	0.000

Table 3.4. Difference Matrix of Sub-Criteria (Social/Economic Conditions)

	dL	du	dL	du	dL	du
City Population	0.000	0.000	-0.066	0.134	0.593	0.776
Income (GDP)	-0.134	0.066	0.000	0.000	0.512	0.696
Tourism Potential	-0.776	-0.593	-0.696	-0.512	0.000	0.000

Third step: Interval multiple matrices (S) are determined using Equations 3.3 and 3.4. Table 3.5 displays the main criteria's S matrix, while Table 3.6. highlights the social/economic conditions' S matrix.

Table 3.5. Interval Multiple (S) Matrix of Main Criteria

	SI	Su	SI	Su	SI	Su	SI	Su
Social /Economic Conditions	1.000	1.000	2.901	4.607	1.530	3.082	0.402	0.812
Cost	0.217	0.345	1.000	1.000	5.607	12.573	0.818	1.874
Demand	0.324	0.654	0.080	0.178	1.000	1.000	1.995	4.732
Competitiveness	1.232	2.490	0.534	1.223	0.211	0.501	1.000	1.000

Table 3.6. Interval Multiple (S) Matrix of Sub-Criteria (Social/Economic Conditions)

	SI	Su	SI	Su	SI	Su
City Population	1.000	1.000	0.795	1.586	7.753	14.608
Income (GDP)	0.630	1.258	1.000	1.000	5.852	11.061
Tourism Potential	0.068	0.129	0.090	0.171	1.000	1.000

Fourth step: Equation 3.5 calculates determinacy values. Table 3.7. displays the main criteria, while Table 3.8. shows social/economic sub-criteria values.

Table 3.7. The Determinacy Value of Main Criteria

	h				h				h				h
Social /Economic Conditions	1.000				0.866				0.797				0.796
Cost	0.866				1.000				0.766				0.760
Demand	0.797				0.766				1.000				0.750
Competitiveness	0.796				0.760				0.750				1.000

Table 3.8. The Determinacy Value of Sub-Criteria (Social/Economic Conditions)

	h	h	h
City Population	1.000	0.800	0.817
Income (GDP)	0.800	1.000	0.816
Tourism Potential	0.817	0.816	1.000

Fifth step: By using Equation 3.6, normalization matrices (t) are computed before criteria weighting. The main criteria normalization matrix is in Table 3.9., while the social/economic conditions matrix is in Table 3.10.

Table 3.9. The Normalization (t) Matrix of Main Criteria

	t	t	t	t
Social /Economic Conditions	1.000	3.251	1.839	0.483
Cost	0.243	1.000	6.965	1.023
Demand	0.390	0.099	1.000	2.523
Competitiveness	1.482	0.667	0.267	1.000

Table 3.10. The Normalization (t) Matrix of Sub-Criteria (Social/Economic Conditions)

	t	t	t
City Population	1.000	0.953	9.130
Income (GDP)	0.755	1.000	6.898
Tourism Potential	0.081	0.107	1.000

Sixth step: By using Equation 3.7, each criterion's normalized priority weight is computed. The main criteria weights, as well as local and global sub-criteria weights, can be found in Table 3.11.

Table 3.11. Weights of Criteria

Main Criteria	Weights	Sub-Criteria	Local Weights	Global Weights
Social /Economic Conditions	28%	City Population	53%	15%
		Income (GDP)	41%	12%
		Tourism Potential	6%	2%
Cost	40%	Distance*Fuel	81%	32%
		Route Cost	19%	8%
Demand	17%	Number of passengers	74%	13%
		Frequency	26%	4%
Competitiveness	15%	Price (Fare)	44%	6%
		Number of Competitors	37%	6%
		Frequency of Competitors	19%	3%

3.5.3. Fuzzy MOORA Method

Three different routes are evaluated using the Fuzzy MOORA approach in this part. With the help of linguistic variables from Table 3.12., six decision-makers evaluate each alternative in relation to each criterion, forming evaluation matrices.

Table 3.12. Linguistic Terms Used for Fuzzy MOORA

Linguistic term	Fuzzy number
Very low (VL)	(0, 0, 0.16)
Low (L)	(0, 0.16, 0.34)
Medium-low (ML)	(0.16, 0.34, 0.5)
Moderate (M)	(0.34, 0.5, 0.66)
Medium-high (MH)	(0.5, 0.66, 0.84)
High (H)	(0.66, 0.84, 1)
Very high (VH)	(0.84, 1, 1)
Ideal (UORP)	(1, 1, 1)

The experts’ subjective evaluations are given in Table 3.13.

Table 3.13. Linguistic Evaluation of The Three Alternative Routes.

		C11	C12	C13	C31	C32	C41	C42	C43	C21	C22
DM1	City1	M	H	MH	MH	ML	H	L	VH	M	M
	City2	ML	MH	H	ML	L	VH	M	M	H	VH
	City3	L	MH	VH	VH	H	VH	VL	VL	M	M
DM2	City1	H	MH	ML	VH	H	H	L	ML	L	M
	City2	VH	MH	VH	MH	H	VH	H	MH	M	M
	City3	M	ML	MH	VH	H	VH	MH	M	M	MH
DM3	City1	VH	M	L	H	H	H	ML	ML	ML	M
	City2	VH	MH	VH	MH	MH	VH	H	MH	M	M
	City3	ML	M	MH	VH	VH	VH	MH	M	M	M
DM4	City1	MH	MH	H	VH	VH	M	M	M	M	M
	City2	M	M	M	M	M	M	M	M	VH	VH
	City3	H	H	VH	MH	MH	M	M	M	MH	MH
DM5	City1	H	H	L	H	VH	VH	MH	MH	M	MH
	City2	L	L	VH	VH	M	VH	M	M	VH	VH
	City3	L	L	VH	VH	M	VH	M	M	VH	VH
DM6	City1	M	H	L	H	VH	H	M	MH	H	MH
	City2	L	ML	VH	VH	VH	VH	M	H	VH	VH
	City3	L	ML	VH	VH	MH	VH	M	H	H	H

The normalization of linguistic assessments is the first step in the Fuzzy MOORA approach (Baleentis et al., 2012). The performance of alternatives in relation to each criterion is evaluated and discussed by experts using linguistic terminology. It is essential to transform these linguistic judgments into numerical values to facilitate future analysis.. The verbal judgments are transformed into a numerical scale during the normalization process, enabling quantitative calculations. Calculating weighted ratings comes after the linguistic evaluations have been normalized. The significance or importance of each criterion in the decision-making process is represented by weighted assessments. The relative weights of the criterion, as identified by the IVPFAHP analysis, are used to determine these weights.. The weighted evaluations show how the alternatives performed generally across all the criteria. The next phase is the Fuzzy MOORA study, which determines fuzzy synthetic utility values (Baleentis et al., 2012). The final step is to rank the possibilities using fuzzy synthetic utility values. The fuzzy synthetic utility values of the alternatives are sorted in descending order, reflecting their relative superiority or preference. The rating enables decision-makers to find the best alternatives and make wise choices.

CHAPTER IV

RESULTS AND DISCUSSIONS

Within this section, we will first examine the results of the Interval-valued Pythagorean Fuzzy AHP. Following that, we will explore the findings obtained through the Fuzzy MOORA method.

4.1. Findings of Interval-Valued Pythagorean Fuzzy AHP

Competitiveness, demand, cost, and socioeconomic conditions are the primary factors taken into account in the AHP study. The decision-making process heavily relies on these criteria. Figure 4.1 gives each criterion's given weights a visual representation. According to the information given, the weights are as follows.

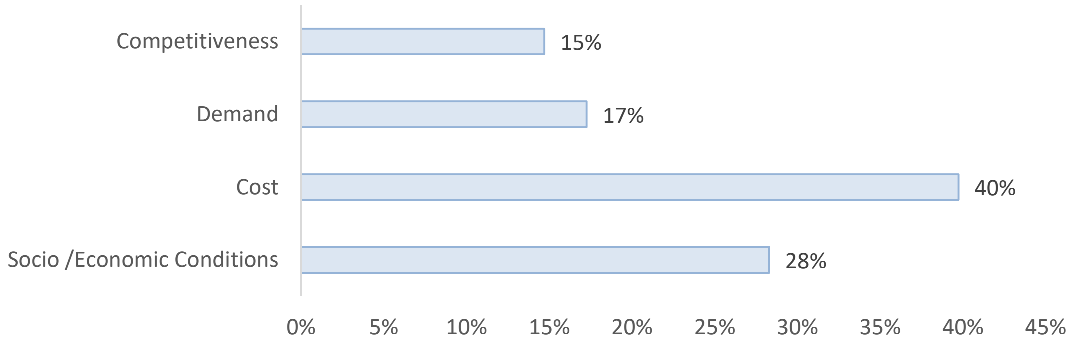

Figure 4.1. Weights of Main Criteria

Cost claims the top spot, commanding 40% of the decision-making process. This underscores the industry's serious awareness of financial effects, as cost-efficient operations are crucial for profitability and sustainability. Economic condition, holding a weight of 28%, emphasizes the intense impact of macroeconomic factors on route selection. Airlines keenly consider economic stability, as it directly affects passenger demand and overall market conditions.

Demand, representing 17%, reflects the industry's responsiveness to passenger needs and preferences. Understanding and anticipating demand patterns is vital for airlines seeking to enhance customer satisfaction and maintain competitive edges. Finally, competitiveness, with a 15% share, acknowledges the dynamic nature of the airline industry. Airlines must strategically position themselves against competitors, considering factors like service quality, route networks, and marketing strategies.

In the next pages, the experts' relative weights for each sub-criterion will be discussed:

Social/Economic Conditions: By assigning distinct weights to city population, income GDP, and tourism potential, decision-makers aim to create a well-balanced and informed strategy, ensuring that new routes align with both immediate market demand and future growth opportunities

Figure 4.2 provides a detailed breakdown of the social/economic criterion; city population, commanding a substantial 53%, stands out as a cornerstone factor. The emphasis on city population underscores its critical importance in shaping air travel demand. Cities with larger populations not only represent a substantial customer base but also signify potential for sustained and robust demand.

Income GDP, with a weight of 41%, reflects the strategic alignment of airlines with economic prosperity. Regions characterized by elevated income levels typically result in heightened spending capacity, stimulating demand for air travel.. Consequently, airlines keenly consider the income GDP of potential destinations to gauge the economic viability of new routes. This sub-criterion serves as a valuable indicator of the financial strength of the target market and its potential for sustaining profitable air services.

Figure 4.2. Weights of Sub-Criteria (Social/Economic Conditions)

Tourism potential comprises a smaller percentage at 6%. Nevertheless, airlines recognize the growing impact of tourism on the aviation industry and are strategically evaluating destinations with available tourism potential.

Cost: Figure 4.3. shows Distance*Fuel, with a significant weight of 81%, emerges as a cornerstone factor in the cost criterion. This sub-criterion highlights the significant impact of the distance a route covers on fuel consumption. Airlines place a strong emphasis on fuel efficiency as it directly correlates with operational costs. Longer distances generally acquire higher fuel expenses, making it imperative for airlines to carefully assess the fuel consumption implications when considering new routes. By assigning such a substantial percentage to Distance*Fuel, decision-makers underscore the strategic importance of optimizing fuel efficiency to manage overall operational costs effectively.

Route Cost, though representing a smaller percentage at 19%, is equally crucial in the cost criterion. This sub-criterion summarizes a broader assessment of the overall expenses associated with establishing and maintaining a new route. It encompasses factors beyond fuel, including maintenance costs, regulatory fees, and other operational expenses. While Distance*Fuel focuses on a specific aspect of cost, Route Cost provides a comprehensive view of the financial implications associated with a new route. Decision-makers allocate a significant but proportionally lesser weight to Route Cost, recognizing its importance in the overall financial equation without overshadowing the critical role of fuel efficiency.

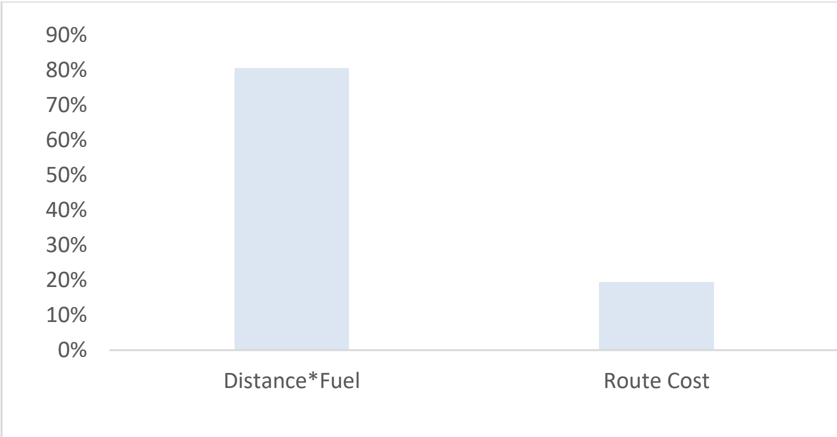

Figure 4.3. Weights of Sub-Criteria (Cost)

Demand: Figure 4.4 provides a comprehensive view of the demand criterion, revealing two critical sub-criteria that significantly influence airline decision-making in new route selection.

The number of Passengers, commanding a substantial 74%, stands out as a primary driver within the demand criterion. More passengers signify a larger potential customer base, suggesting strong market demand. By allocating a significant percentage to the Number of Passengers, airlines emphasize their commitment to serving large and potentially lucrative markets. The goal is to maximize revenue and enhance the overall viability of new routes by prioritizing destinations with significant passenger potential.

Frequency, though representing a smaller percentage at 26%, holds its own importance within the demand criterion. This sub-criterion focuses on the regularity and consistency of passenger demand, emphasizing the need for sustained interest in a given route. While fewer passengers may use a route less frequently, a steady and predictable stream of travelers is crucial for the profitability and stability of a route. Airlines recognize the significance of maintaining a certain frequency to ensure consistent revenue generation.

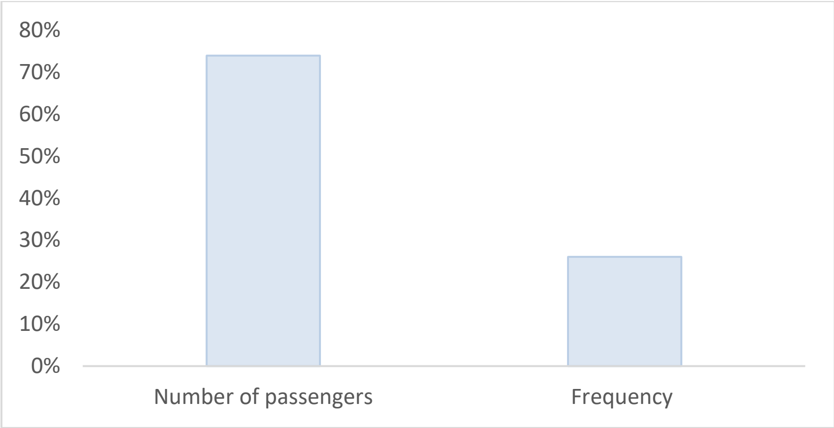

Figure 4.4. Weight of Sub-Criteria (Demand)

Competitiveness: Figure 4.5 shows the competitiveness criterion for airline route selection, outlining three key sub-criteria: Price (44%), Number of Competitors (37%), and Frequency of Competitors (19%). Price is a crucial factor in airline route selection. As the number of competitors increases, airlines may lower their prices to maintain or increase their market share. This can lead to a competitive pricing environment, where airlines adjust their fares based on the number of competitors and the demand for the route.

The number of competitors on a given route can impact the profitability and feasibility of airline operations. Routes with higher competition may have lower prices due to increased pressure from competitors. Airlines may adjust their flight schedules to minimize the impact of competitors or to maximize their market share.

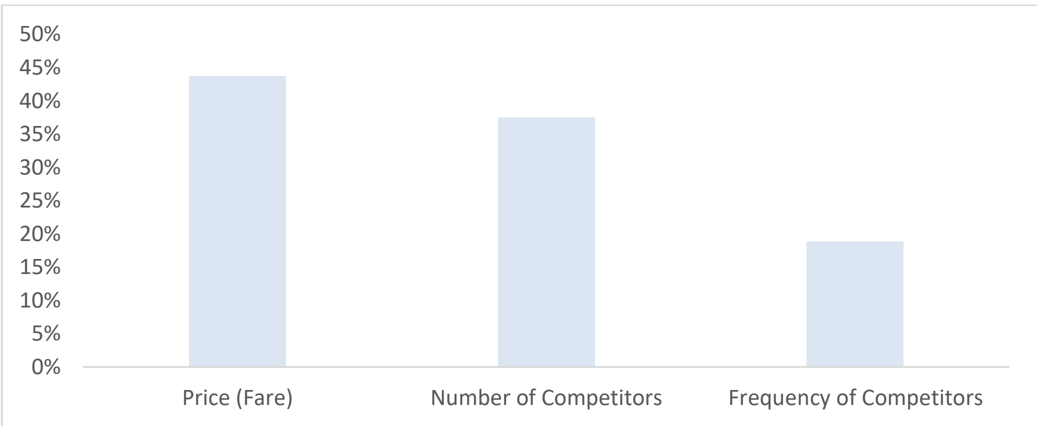

Figure 4.5. Weights of Sub-Criteria (Competitiveness)

4.2. MOORA Analysis Results

We may analyze the findings to comprehend the preferences and ranks of the alternatives based on the MOORA study. The average assessments and the relative effectiveness of the alternatives across the criteria are taken into account throughout the interpretation (Baleentis et al., 2012). The normalized fuzzt evaluations are given in Table 4.1.

Table 4.1. Normalized Fuzzy Evaluations

City	A	b	c
City 1	0.1037	0.1232	0.1340
City 2	0.0093	0.0278	0.0526
City 3	0.0304	0.0478	0.0607

We take into account their average evaluations when comparing the rankings of the alternatives based on the MOORA study. The rankings shed light on the general effectiveness and preferred qualities of the option (Table 4.2).

Table 4.2. MOORA Rankings of the Alternatives

Rank	**Alternative**
1	City 2
2	City 1
3	City 3

City 2 comes out on top among the alternatives, demonstrating superior performance and choice in light of the considered factors. In comparison to other cities, it consistently earns superior average ratings across the majority of criteria. City 1 achieves the second spot, demonstrating a comparatively solid performance. City 3 exhibits strengths in several aspects while receiving the lowest score. In order to prioritize and concentrate on the top-ranked alternatives during the decision-making process, these rankings offer decision-makers useful information (Baleentis et al., 2012). Before making a final decision on the alternative, it is important to take into account additional variables and contextual considerations. In order to make an informed choice, it is important to integrate the rankings obtained from the MOORA analysis with additional factors and stakeholder input (Bakir et al., 2021). Based on the weighted evaluations of the criteria, the MOORA analysis offers a thorough evaluation of the options. The statistical analysis, findings interpretation, and rating comparison improve decision-makers comprehension of the decision-making process and offer insightful information.

4.2.1. Comparison with Other Studies

The comparison highlights commonalities and differences between this study and (Koma, 2022), providing insights into their respective approaches to criteria weighting in the airline route selection process using the AHP approach; both studies share commonalities in recognizing the importance of social/economic conditions, cost considerations, demand factors, and competitiveness. However, there are differences in the specific weights assigned to these criteria as follows:

- Both studies recognize the importance of social/economic conditions, with an emphasis on city population, income (GDP), and tourism potential. (Koma, 2022) assigns a total weight of 15% to social-economic conditions, whereas this assigns a higher weight of 28%.
- Both studies emphasize cost criteria; this study places a higher overall weight on the cost category (43%) compared to (Koma, 2022) (40%).
- Both studies prioritize passenger volume in the demand category; there are variations in the overall weight, which is higher in this study (33%) compared to (Koma, 2022) (17%). That places more emphasis on the number of business passengers.
- The overall weight for competitiveness increased from 9% in this study to 15%. (Koma, 2022). There was a notable increase in the emphasis on "Price (Fare)" (44%), highlighting a greater focus on pricing as a competitive factor.

The differences could stem from variations in sub-criteria selection and preferences of decision-makers involved in the route selection process. Decision-makers should carefully consider these differences when interpreting and applying the results, as they may impact the prioritization of criteria and the subsequent decision-making process in airline route selection.

4.3. Implications and Significance of the Findings

The conclusions from the analysis of the MOORA and AHP data have important implications for decision-making. Decision-makers have more faith in the evaluation of alternatives since the rankings between the two methods are constant (Sagnak et al., 2022). City 2, which received the highest ranking, regularly exhibits superior performance and preference across all of the considered factors. This result suggests that City 2 should be given priority in decision-making. The disparities in rankings between AHP and MOORA further emphasize how important it is to take into account various evaluation techniques (Mokarrari & Torabi, 2021). These variances can result from differing data scales and data interpretation techniques, as well as from the various mathematical operations used in the methodologies. Decision-makers can acquire a more thorough understanding of the options and minimize the drawbacks of individual techniques by combining AHP and MOORA. The results importance lies in how they help people make well-informed decisions. The rankings produced by AHP and MOORA give decision-makers insightful information about the advantages and disadvantages of the alternatives. These insights can guide resource allocation, investment decisions, and the selection of the optimal option based on the preferences and priorities of the decision-makers.

The outcomes of the AHP and MOORA should, however, take into account additional considerations, including stakeholder input, practicality, and financial constraints (Bae et al., 2021). Recognizing and addressing each methodology's flaws is also crucial to improving the accuracy and dependability of the assessments.

CHAPTER V

CONCLUSION

The aim of the study was to assess and rank three alternatives (city1, city2, and city3) according to a set of criteria using the Analytic Hierarchy Process (AHP) and Multiple Objective Optimization based on Ratio Analysis (MOORA) techniques. The research's methodological methodology included data collection, criteria selection, AHP analysis, MOORA ranking, and outcome comparison.

In summary, this research has successfully accomplished all the objectives outlined in Chapter One. The model effectively translates decision-makers subjective experiences from the linguistic form to the numerical domain using Pythagorean Fuzzy Numbers. Additionally, through a meticulous examination, the research identifies and assesses the significance of factors influencing route selection, employing Interval-valued Pythagorean Fuzzy AHP. The subsequent determination of weights for the chosen factors enhances the overall understanding of the decision-making process in this context; then, the alternative routes are ranked by MOORA.

5.1. Contribution

Two popular multi-criteria decision-making techniques, the AHP and MOORA, offer important insights into the assessment and ranking of alternatives. The results indicate the parallels and variations in rankings and offer suggestions for making decisions. Decision-makers can make well-informed choices that fit their goals and priorities by taking into the unique context and requirements.

5.2. Limitation and Future Work

on the Basis of Ratio Analysis (MOORA) methodologies for assessing and ranking alternatives have been usefully explained by the current study as decision-maker assessments are used as the foundation for the AHP and MOORA techniques. However, there is a possible area for additional study and development that could increase the potency and usefulness of these approaches, which is validation and comparison with real-world outcomes: Future studies can compare the ranks produced by the AHP and MOORA approaches with actual results or performance measurements to further validate the methodologies. Researchers can evaluate the prediction strength and accuracy of the approaches in real-world decision-making settings by looking at the correlation between the anticipated rankings and actual performance.

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APPENDIXES

APPENDIX A

Table A.1. Airline Route Selection Pairwise Comparison Questionnaire

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route.

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions					Social conditions of the route.
Cost					The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand					Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.

Social/	City Population	Income (GDP)	Tourism Potential	Description
City Population				The catchment areas will give information about the estimated demand.
Income (GDP)				Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential				The high tourism potential of the destination points is an advantage for airlines.

Cost	Distance*Fuel	Route Cost	Description
Distance*Fuel			The flight distance of the route and the quantity of fuel used for the route.
Route Cost			The cost is other than distance *fuel.

Demand	Number of passengers	Frequency	Description
Number of Passengers			Number of existing passengers from the related airport based on the historical data
Frequency			The number of flights operated by the airline.

Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors	Description
Price (Fare)				The average fare of other airlines operates on this route.
Number of Competitors				The number of airlines that operate on this route.
Frequency of Competitors				The number of flights operated by other airlines.

Table A.2. Airline Route Selection Pairwise Comparison Questionnaire (DM1)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route.

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		AI	AI	AI	Social conditions of the route.
Cost			VHI	AAI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				AAI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.
Social/	City Population	Income (GDP)	Tourism Potential		Description
City Population		A1	VHI		The catchment areas will give information about the estimated demand.
Income (GDP)			CHI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential					The high tourism potential of the destination points is an advantage for airlines.
Cost	Distance*Fuel	Route Cost			Description
Distance*Fuel		HI			The flight distance of the route and the quantity of fuel used for the route.
Route Cost					The cost is other than distance *fuel.
Demand	Number of passengers		Frequency		Description
Number of Passengers			AAI		Number of existing passengers from the related airport based on the historical data
Frequency					The number of flights operated by the airline.
Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors		Description
Price (Fare)		AI	AAI		The average fare of other airlines operates on this route.
Number of Competitors			AI		The number of airlines that operate on this route.
Frequency of Competitors					The number of flights operated by other airlines.

Table A.3. Airline Route Selection Pairwise Comparison Questionnaire (DM2)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route.

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		AI	AAI	AI	Social conditions of the route.
Cost			HI	AI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				AAI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.

Social/	City Population	Income (GDP)	Tourism Potential	Description
City Population		A1	CHI	The catchment areas will give information about the estimated demand.
Income (GDP)			VHI	Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential				The high tourism potential of the destination points is an advantage for airlines.

Cost	Distance*Fuel	Route Cost	Description
Distance*Fuel		HI	The flight distance of the route and the quantity of fuel used for the route.
Route Cost			The cost is other than distance *fuel.

Demand	Number of passengers	Frequency	Description
Number of Passengers		AAI	Number of existing passengers from the related airport based on the historical data
Frequency			The number of flights operated by the airline.

Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors	Description
Price (Fare)		AI	AI	The average fare of other airlines operates on this route.
Number of Competitors			AAI	The number of airlines that operate on this route.
Frequency of Competitors				The number of flights operated by other airlines.

Table A.4. Airline Route Selection Pairwise Comparison Questionnaire (DM3)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route.

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		AAI	AAI	AI	Social conditions of the route.
Cost			VHI	AI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				HI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.

Social/	City Population	Income (GDP)	Tourism Potential	Description
City Population		A1	CHI	The catchment areas will give information about the estimated demand.
Income (GDP)			HI	Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential				The high tourism potential of the destination points is an advantage for airlines.

Cost	Distance*Fuel	Route Cost	Description
Distance*Fuel		HI	The flight distance of the route and the quantity of fuel used for the route.
Route Cost			The cost is other than distance *fuel.

Demand	Number of passengers	Frequency	Description
Number of Passengers		AAI	Number of existing passengers from the related airport based on the historical data
Frequency			The number of flights operated by the airline.

Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors	Description
Price (Fare)		AI	AI	The average fare of other airlines operates on this route.
Number of Competitors			AAI	The number of airlines that operate on this route.
Frequency of Competitors				The number of flights operated by other airlines.

Table A.5. Airline Route Selection Pairwise Comparison Questionnaire (DM4)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		CHI	VHI	VLI	Social conditions of the route.
Cost			VHI	LI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				HI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.
Social/	City Population	Income (GDP)	Tourism Potential		Description
City Population		HI	CHI		The catchment areas will give information about the estimated demand.
Income (GDP)			AAI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential					The high tourism potential of the destination points is an advantage for airlines.
Cost	Distance*Fuel	Route Cost			Description
Distance*Fuel		CHI			The flight distance of the route and the quantity of fuel used for the route.
Route Cost					The cost is other than distance *fuel.
Demand	Number of passengers		Frequency		Description
Number of Passengers			AAI		Number of existing passengers from the related airport based on the historical data
Frequency					The number of flights operated by the airline.
Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors		Description
Price (Fare)		HI	AI		The average fare of other airlines operates on this route.
Number of Competitors			VHI		The number of airlines that operate on this route.
Frequency of Competitors					The number of flights operated by other airlines.

Table A.6. Airline Route Selection Pairwise Comparison Questionnaire (DM5)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		AI	AI	AI	Social conditions of the route.
Cost			HI	HI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				HI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.
Social/	City Population	Income (GDP)	Tourism Potential		Description
City Population		A1	HI		The catchment areas will give information about the estimated demand.
Income (GDP)			VHI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential					The high tourism potential of the destination points is an advantage for airlines.
Cost	Distance*Fuel	Route Cost			Description
Distance*Fuel		AAI			The flight distance of the route and the quantity of fuel used for the route.
Route Cost					The cost is other than distance *fuel.
Demand	Number of passengers		Frequency		Description
Number of Passengers			HI		Number of existing passengers from the related airport based on the historical data
frequency					The number of flights operated by the airline.
Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors		Description
Price (Fare)		AAI	VHI		The average fare of other airlines operates on this route.
Number of Competitors			VHI		The number of airlines that operate on this route.
Frequency of Competitors					The number of flights operated by other airlines.

Table A.7. Airline Route Selection Pairwise Comparison Questionnaire (DM6)

We express our gratitude in advance for your valuable contribution and expertise in this conducted study aimed at selecting a new airline route. At this stage of the study, we kindly request your opinions to determine the degrees of importance for the criteria utilized in the selection process of the new route

In the following five pair-wise comparison tables, please complete only the designated fields highlighted in green, based on your subjective evaluation using the provided coding scale. For instance, when evaluating the relative importance of "Social/Political Criteria" compared to "Cost Criteria" in the context of route selection, if you believe that "Social/Political Criteria" is of "very low importance" in comparison to "Cost Criteria," please input "VLI" in the E20 cell. This indicates that the importance of Social/Political Criteria falls within the range of 10%-20%, while the importance of Cost Criteria falls within the range of 90%-100% when comparing these two criteria. We sincerely appreciate your support and participation in this endeavor.

Route Selection	Social /Economic Conditions	Cost	Demand	Competitiveness	Description
Social conditions		HI	AAI	BAI	Social conditions of the route.
Cost			VHI	AAI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
Demand				AAI	Total passenger demand of the route.
Competitiveness					Comparison with the other airlines based on the route.

Social/	City Population	Income (GDP)	Tourism Potential	Description
City Population		AAI	AAI	The catchment areas will give information about the estimated demand.
Income (GDP)			AAI	Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
Tourism Potential				The high tourism potential of the destination points is an advantage for airlines.

Cost	Distance*Fuel	Route Cost	Description
Distance*Fuel		VHI	The flight distance of the route and the quantity of fuel used for the route.
Route Cost			The cost is other than distance *fuel.

Demand	Number of passengers	Frequency	Description
Number of Passengers		VHI	Number of existing passengers from the related airport based on the historical data
Frequency			The number of flights operated by the airline.

Competitiveness	Price (Fare)	Number of Competitors	Frequency of Competitors	Description
Price (Fare)		VHI	AAI	The average fare of other airlines operates on this route.
Number of Competitors			AAI	The number of airlines that operate on this route.
Frequency of Competitors				The number of flights operated by other airlines.

APPENDIX B

Table B.1. The Pairwise Comparison Matrix of Main Criteria with PFNs

		Social /Economic Conditions				Cost				Demand				Competitiveness			
		μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU
DM1	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55
	Cost	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45
	Demand	0.45	0.55	0.45	0.55	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45
	Competitiveness	0.45	0.55	0.45	0.55	0.35	0.45	0.55	0.65	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965
DM2	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.55	0.65	0.35	0.45	0.45	0.55	0.45	0.55
	Cost	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35	0.45	0.55	0.45	0.55
	Demand	0.35	0.45	0.55	0.65	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45
	Competitiveness	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965
DM3	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45	0.55	0.65	0.35	0.45	0.45	0.55	0.45	0.55
	Cost	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2	0.45	0.55	0.45	0.55
	Demand	0.35	0.45	0.55	0.65	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35
	Competitiveness	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965
DM4	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.9	1	0	0	0.8	0.9	0.1	0.2	0.1	0.2	0.8	0.9
	Cost	0	0	0.9	1	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2	0.2	0.35	0.65	0.8
	Demand	0.1	0.2	0.8	0.9	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35
	Competitiveness	0.8	0.9	0.1	0.2	0.65	0.8	0.2	0.35	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965
DM5	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55	0.45	0.55
	Cost	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35	0.65	0.8	0.2	0.35
	Demand	0.45	0.55	0.45	0.55	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35
	Competitiveness	0.45	0.55	0.45	0.55	0.2	0.35	0.65	0.8	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965
DM6	Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35	0.55	0.65	0.35	0.45	0.35	0.45	0.55	0.65
	Cost	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2	0.55	0.65	0.35	0.45
	Demand	0.35	0.45	0.55	0.65	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45
	Competitiveness	0.55	0.65	0.35	0.45	0.35	0.45	0.55	0.65	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965

Table B.2. The Pairwise Comparison Matrix of Social/Economic Conditions Sub-Criteria with PFNs

		City Population				Income (GDP)				Tourism Potential			
	Social/Economic Conditions	μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU
DM1	City Population	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.8	0.9	0.1	0.2
	Income (GDP)	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.9	1	0	0
	Tourism Potential	0.1	0.2	0.8	0.9	0	0	0.9	1	0.1965	0.1965	0.1965	0.1965
DM2	City Population	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.9	1	0	0
	Income (GDP)	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2
	Tourism Potential	0	0	0.9	1	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965
DM3	City Population	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.9	1	0	0
	Income (GDP)	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35
	Tourism Potential	0	0	0.9	1	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965
DM4	City Population	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.9	1	0	0
	Income (GDP)	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.65	0.8	0.2	0.35
	Tourism Potential	0	0	0.9	1	0.2	0.35	0.65	0.8	0.1965	0.1965	0.1965	0.1965
	City Population	0.1965	0.1965	0.1965	0.1965	0.45	0.55	0.45	0.55	0.65	0.8	0.2	0.35
DM5	Income (GDP)	0.45	0.55	0.45	0.55	0.1965	0.1965	0.1965	0.1965	0.8	0.9	0.1	0.2
	Tourism Potential	0.2	0.35	0.65	0.8	0.1	0.2	0.8	0.9	0.1965	0.1965	0.1965	0.1965
DM6	City Population	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45	0.55	0.65	0.35	0.45
	Income (GDP)	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965	0.55	0.65	0.35	0.45
	Tourism Potential	0.35	0.45	0.55	0.65	0.35	0.45	0.55	0.65	0.1965	0.1965	0.1965	0.1965

Table B.3. Aggregating Pairwise Comparison of Main Criteria

	Social /Economic Conditions				Cost				Demand				Competitiveness			
	μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU
Social /Economic Conditions	0.1965	0.1965	0.1965	0.1965	0.5553	0.6650	0.0000	0.0000	0.5476	0.6491	0.3089	0.4203	0.3359	0.4494	0.5121	0.6139
Cost	0.0000	0.0000	0.5553	0.6650	0.1965	0.1965	0.1965	0.1965	0.7465	0.8653	0.1260	0.2410	0.4469	0.5741	0.3844	0.5078
Demand	0.3089	0.4203	0.5476	0.6491	0.1260	0.2410	0.7465	0.8653	0.1965	0.1965	0.1965	0.1965	0.5979	0.7211	0.2646	0.3969
Competitivenes s	0.5121	0.6139	0.3359	0.4494	0.3844	0.5078	0.4469	0.5741	0.2646	0.3969	0.5979	0.7211	0.1965	0.1965	0.1965	0.1965

Table B.4. Aggregating Pairwise Comparison of Sub-Criteria (Social/Economic Conditions)

	City Population				Income (GDP)				Tourism Potential			
	μL	μU	νL	νU	μL	μU	νL	νU	μL	μU	νL	νU
City Population	0.1965	0.1965	0.1965	0.1965	0.4653	0.5655	0.4315	0.5319	0.7700	0.8811	0.0000	0.0000
Income (GDP)	0.4315	0.5319	0.4653	0.5655	0.1965	0.1965	0.1965	0.1965	0.7152	0.8342	0.0000	0.0000
Tourism Potential	0.0000	0.0000	0.7700	0.8811	0.0000	0.0000	0.7152	0.8342	0.1965	0.1965	0.1965	0.1965

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