

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

MASTER THESIS

**AIRLINE NEW ROUTE SELECTION WITH
PYTHAGOREAN FUZZY AHP AND WASPAS
METHODS**

ŞENAY KOMA

**THESIS SUPERVISOR
ASSOC. PROF. ALİ OSMAN KUŞAKCI**

ISTANBUL, 2022

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PYTHAGOREAN FUZZY AHP AND WASPAS
METHODS**

by

ŞENAY KOMA

**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

ASSOC. PROF. ALİ OSMAN KUŞAKCI

ISTANBUL, 2022

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

Assoc. Prof. Ali Osman Kuşakcı

Prof.Dr. Mustafa Kemal Yılmaz

Assoc.Prof. Berk Ayvaz

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

Date of Submission

Seal/Signature

ACADEMIC HONESTY ATTESTATION

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: Şenay KOMA

Signature:



ÖZ

PİSAGOR BULANIK ANALİTİK HİYERARŞİ PROSES VE WASPAS
YÖNTEMLERİ İLE HAVAYOLU YENİ ROTA SEÇİMİ

Koma, Şenay

Hava Taşımacılığı Yönetimi Yüksek Lisans Programı

Öğrenci Numarası:204038013

Open Researcher and Contributor ID (ORC-ID): 0000-0002-2840-0634

Ulusal Tez Merkezi Referans Numarası: 10476059

Tez Danışmanı: Doç. Dr. Ali Osman Kuşakcı

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Yeni rota seçimi Havayolu şirketlerinin temel karar verme problemlerinden biridir. Çoklu rota değerlendirmede optimum rotayı seçmek için birçok araç ve program kullanılmaktadır. Geçmişte havayolu rota seçim kararını modellemek için çeşitli yaklaşımlar kullanılmıştır. Havayolu rota seçimi problemi, birbiriyle çelişen birçok kriter ve alternatif güzergahın yanı sıra çelişkili ve karmaşık yargıları barındırdığından karmaşık bir ÇKKV problemi olarak değerlendirilebilir. Bu karmaşık ve çok boyutlu problem için, bu çalışmada Aralık-Değerli Pisagor Bulanık AHP ve Aralık-Değerli Pisagor Bulanık WASPAS yöntemleri kullanılarak hibrit bir ÇKKV yaklaşımı önerilmiştir. Alternatif farklı destinasyonların belirli kriterler üzerinden değerlendirildiği bir havayolu rota seçim modeli oluşturulmuştur. Değerlendirme kriterlerinin önem ağırlıklarının belirlenmesi için Pisagor FAHP, alternatiflerin değerlendirilmesinde ise Pisagor Bulanık WASPAS yöntemi kullanılmıştır. Literatür taramasına ve havayolu rota planlama uzmanlarının görüşlerine bağlı olarak ana değerlendirme kriterleri sosyal/ekonomik koşullar, maliyet, talep ve rekabet gücü olarak belirlenmiştir. Ayrıca şehir nüfusu, gelir ve ticaret, turizm potansiyeli, uzaklık, rota maliyeti, ekonomi/business/bağlantılı yolcu sayıları, kargo kapasitesi, rakip havayolları sayısı, rakip havayollarının uçuş frekansları ve rakip havayollarının bilet ücretleri çalışmanın alt kriterleri olarak belirlenmiştir. Kriterler üzerinde uzmanların yapmış olduğu ikili karşılaştırmalar Pisagor bulanık sayılara dönüştürülerek Pisagor Bulanık AHP ile kriter ağırlıkları belirlenmiştir. İkili kıyaslama sonuçlarına göre,

maliyetinin (%43 ağırlık) ve talebin (%33 ağırlık) rota seçim kararını sosyal/ekonomik koşullardan (%15 ağırlık) ve rekabet gücünden (%9 ağırlık) daha fazla etkilediğini görülmüştür. Ağırlıklı kriterler üzerinden alternatif beş rota havayolu uzmanları tarafından değerlendirilmiş ve optimum rota Pisagor Bulanık WASPAS kullanılarak seçilmiştir. Çalışmada sunulan bu hibrit ÇKKV metodu, havayolu yeni rota seçimi problemine uygulanabilir bir çözüm sunmaktadır.

Anahtar Kelimeler: Aralık-Değerli Pisagor Bulanık Analitik Hiyerarşi Prosesi, Aralık-Değerli Pisagor Bulanık WASPAS, Çok Kriterli Karar Verme Yöntemleri, Havayolu Yeni Hat Seçimi.



ABSTRACT

AIRLINE NEW ROUTE SELECTION WITH PYTHAGOREAN FUZZY AHP AND WASPAS METHODS

Koma, Senay

MSc in Air Transport Management

Student ID: 204038013

Open Researcher and Contributor ID (ORCID): 0000-0002-2840-0634

National Thesis Center Reference Number: 10476059

Thesis Supervisor: Assoc. Prof. Ali Osman Kuşakcı

July 2022, 78 Pages

Where to fly is one of the core decision problems of the airline industry. Many programs and tools are used to perform multiple route evaluations to select the optimum route. Previous studies on the subject of airline route selection have used varied methodologies to solve the problem. The airline route selection problem can be interpreted as a complex Multi-Criteria Decision Making (MCDM) problem because it concerns many conflicting criteria and alternative routes, with contradictory and complex judgments. To deal with these difficulties, a hybrid MCDM approach is proposed in this study by using Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS methods. Decision analysis is applied for selecting a new route between different alternative routes by evaluating them with selection criteria. Pythagorean Fuzzy AHP is used for weighting criteria, and Pythagorean Fuzzy WASPAS is used for assessing alternatives. According to the literature review and the experts' opinion, the selection criteria are determined as social/economic conditions, cost, demand, and competitiveness are the main criteria where city population, income/trade, tourism potential, distance, route cost, number of economy passenger, number of business passenger, number of connecting passenger, cargo capacity, number of competitor airlines, frequency of competitor airlines and price of competitor airlines are the sub-criteria of the study. The pair-wise linguistic comparisons of selection criteria are transferred into Pythagorean fuzzy numbers (PFNs) to weigh each criterion's importance. The results of these comparisons show

that the main criteria cost (43% weight) and demand (33% weight) impact route selection decisions more than social/economic conditions (15% weight) and competitiveness (9% weight). Regarding the criteria, the alternative five routes are evaluated by the route development experts, and the best route is selected with Pythagorean Fuzzy WASPAS. This hybrid MCDM methodology presents a feasible solution to the problem.

Keywords: Airline New Route Selection, Interval-Valued Pythagorean Fuzzy Analytic Hierarchy Process, Interval-Valued Pythagorean Fuzzy WASPAS, Multi-Criteria Decision Making Methods.



DEDICATION

It is dedicated to my mother, father, and lovely family.



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Firstly, I would like to express my thanks and respect to my thesis supervisor Assoc. Prof. Ali Osman Kuşakcı for his support, guidance, and contributions to my study.

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TABLE OF CONTENTS

ÖZ	iv
ABSTRACT	vi
DEDICATION	viii
ACKNOWLEDGEMENT	ix
TABLE OF CONTENTS	x
LIST OF TABLE	xii
LIST OF FIGURES	xiv
LIST OF SYMBOLS AND ABBREVIATIONS	xv
CHAPTER I INTRODUCTION	1
1.1. Research Problem.....	2
1.2. Research Objectives and Research Questions.....	2
1.3. Research Novelty	3
1.4. Research Structure.....	4
CHAPTER II LITERATURE REVIEW	5
2.1. Airline Route Selection Methodologies	5
2.2. Multi-Criteria Decision-Making Application in Airline Industry.....	9
2.3. MCDM Applications of Airline Route Selection Problem	11
2.4. Selection Criteria for Evaluating A New Route	13
CHAPTER III METHODOLOGY & APPLICATION	17
3.1. Methodological Framework	18
3.2. Fuzzy Sets.....	19
3.2.1. Intuitionistic Fuzzy Sets (IFS).....	19
3.2.2. Pythagorean Fuzzy Sets (PFS)	20
3.2.3. The Preference for Pythagorean Fuzzy Numbers.....	23
3.3. Interval-Valued Pythagorean Fuzzy AHP.....	24
3.4. Interval-Valued Pythagorean Fuzzy WASPAS Method	26

3.5. Application of Proposed Method to Airline Route Selection Problem	29
3.5.1. Selecting Criteria and Alternative Routes	29
3.5.2. Application of Interval-Valued Pythagorean Fuzzy AHP	35
3.5.3. Application of Interval-Valued Pythagorean Fuzzy WASPAS Method	39
CHAPTER IV RESULTS & DISCUSSION.....	43
4.1. Findings of Interval-Valued Pythagorean Fuzzy AHP.....	43
4.2. Findings of Interval-Valued Pythagorean Fuzzy WASPAS Method	48
CHAPTER V CONCLUSIONS	50
5.1. Contributions	51
5.2. Limitations and Future Work	51
REFERENCES.....	52
APPENDIXES	58
APPENDIX A	58
APPENDIX B	68
APPENDIX C	73
CURRICULUM VITAE.....	78

LIST OF TABLES

Table 2.1. Approaches Used for Airline Route Selection	8
Table 2.2. Studies Used MCDM Methods in Airline Industry	11
Table 2.3. Studies Used MCDM Methods in Airline Route Selection	13
Table 2.4. Criteria Used for Route Selection	16
Table 3.1. Linguistic Scale for Interval-Valued Pythagorean FAHP	25
Table 3.2. Linguistic Terms for Evaluating Alternatives.....	27
Table 3.3. Evaluation Criteria and Descriptions	32
Table 3.4. Difference Matrix of Main Criteria.....	36
Table 3.5. Difference Matrix of Sub-criteria (Social/Economic Conditions).....	36
Table 3.6. Interval Multiple (S) Matrix of Main Criteria.....	37
Table 3.7. Interval Multiple (S) Matrix of Sub-criteria (Social/Economic Conditions)	37
Table 3.8. The Determinacy Value of Main Criteria	37
Table 3.9. The Determinacy Value of Sub-criteria (Social/Economic Conditions) ..	38
Table 3.10. The Normalization (t) Matrix of Main Criteria.....	38
Table 3.11. The Normalization (t) Matrix of Sub-criteria (Social/Economic Conditions) ...	38
Table 3.12. Weights of Criteria.....	39
Table 3.13. Linguistic Evaluation of Five Alternative Routes.....	40
Table 3.14. Normalization Matrix and Maximum Values	41
Table 3.15. Ranking of Alternatives	41
Table 3.16. Ranking of Alternative with Changing of λ Values.....	42
Table 4.1. Ranking of Five Alternative Routes.....	49
Table A.1. Airline Route Selection Pairwise Comparison Questionnaire	58
Table A.2. Airline Route Selection Pairwise Comparison Questionnaire (DM1)	59
Table A.3. Airline Route Selection Pairwise Comparison Questionnaire (DM2)	60
Table A.4. Airline Route Selection Pairwise Comparison Questionnaire (DM3)	61
Table A.5. Airline Route Selection Pairwise Comparison Questionnaire (DM4)	62
Table A.6. Airline Route Selection Pairwise Comparison Questionnaire (DM5)	63
Table A.7. Airline Route Selection Pairwise Comparison Questionnaire (DM6)	64
Table A.8. Airline Route Selection Pairwise Comparison Questionnaire (DM7)	65
Table A.9. Airline Route Selection Pairwise Comparison Questionnaire (DM8)	66
Table A.10. Airline Route Selection Pairwise Comparison Questionnaire (DM9) ...	67
Table B.1. The Pairwise Comparison Matrix Of Main Criteria With PFNs.....	68

Table B.2. The Pairwise Comparison Matrix of Social/Economic Conditions Sub-Criteria Criteria With PFNs	70
Table B.3. Aggregating Pairwise Comparison Of Main Criteria.....	72
Table B.4. Aggregating Pairwise Comparison Of Sub-Criteria (Social/Economic Conditions).....	72
Table C.1. Group Decision Matrix Of Alternative Route Evaluation.....	73
Table C.2. Pythagorean Fuzzy Normalized Decision Matrix	74
Table C.3. The Calculation of WSM	75
Table C.4. WSM Values for Each Alternative.....	76
Table C.5. Calculation of WPM.....	76
Table C.6. WPM Values of Each Alternative	77



LIST OF FIGURES

Figure 1.1. Total Passenger Traffic.....	2
Figure 2.1. Criteria Used for Route Selection.....	14
Figure 3.1. Design of the Proposed Method	18
Figure 3.2. The Comparison of IFNs Space and PFNs Space	24
Figure 3.3. The Hierarchy of Route Selection Problem.....	31
Figure 3.4. The Five Alternative Routes.....	33
Figure 3.5. The Annual Change in GDP for SEA, DFW, and DEN 2022.....	34
Figure 4.1. Weights of Main Criteria.....	43
Figure 4.2. Weights of Sub-criteria (Social/Economic Conditions)	44
Figure 4.3. Weights of Sub-criteria (Cost).....	45
Figure 4.4. Percentage Share of Expenditure of Fuel Cost in Total Cost from 2011 to 2022.....	46
Figure 4.5. Weights of Sub-criteria (Demand).....	46
Figure 4.6. Weights of Sub-criteria (Competitiveness)	48
Figure 4.7. The Effect of Changing λ Values on Route Ranking	49

LIST OF SYMBOLS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
DEMATEL	Decision-Making Trial and Evaluation Laboratory
ELECTRE	Elimination and Choice Expressing Reality
FAHP	Fuzzy Analytic Hierarchy Process
FMAGDM	Fuzzy Multi-attribute Group Decision Making
FTOPSIS	Fuzzy Technique for Order Preference by Similarity to An Ideal Solution
GRA	Grey Relational Analysis
IFN	Intuitionistic Fuzzy Number
IFS	Intuitionistic Fuzzy Set
IVIF	Interval-Valued Intuitionistic Fuzzy
IVPF	Inter-Valued Pythagorean Fuzzy
MAS	Multi-Airport System
MCDM	Multi-criteria Decision Making
MOA	Market Opportunity Analysis
MOGP	Multi-Objective Goal Programming
MULTIMOORA	Multi-Objective Optimization by Ratio Analysis
OCBA	Optimal Computing Budget Allocation
PFS	Pythagorean Fuzzy Set
PFWA	Pythagorean Fuzzy Weighted Averaging
PF-WASPAS	Pythagorean Fuzzy Weighted Aggregated Sum Product Assessment
RPC	Rank Pair-Wise Comparison
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje
WASPAS	Weighted Aggregated Sum Product Assessment
WPM	Weighted Product Model
WSM	Weighted Sum Model
I	Symbol of IFS
μ	Degree of membership

ν	Degree of non-membership
P	Symbol of PFS
π	Determinacy value
w_i	Weight
c_{ij}	Selection criterion
a_{ij}	Performance value
$D(a_{ij})$	Decision matrix
$A(a_{ij})$	Pairwise comparison matrix
$D(d_{ik})$	Difference matrix
$S(s_{ik})$	Interval multiplicative matrix
T_{ik}	Weight matrix
Q_i^1	WSM value
Q_i^2	WPM value
Σ	Sum operation
Π	Product operation
λ	WASPAS parameter
DM	Decision maker
EDM	Expert decision maker

CHAPTER I

INTRODUCTION

Considering the global aviation industry, which is continuously expanding, we could say that it has an important mission of connecting countries and continents. It not only creates an economic revival for itself but also empowers related industries such as aircraft production, airport relevant issues, etc. The improvement of the industry continues depending on global innovations and technological developments. Also, the world's social, economic, and political structure impacts the airline industry (Belobaba et al., 2016).

On the other hand, the aviation industry faced many challenges and difficulties over the past decades, such as oil prices, economic crisis, security issues, and finally, the greatest effect, the Covid-19 pandemic. Although all these factors and challenges decrease the industry's growing acceleration, it can carry on going forward.

Moreover, the development of world air transport has increased by 5% over the past 30 years. The growth in air transportation has been twice the growth of gross domestic product (GDP). Even under relatively conservative assumptions for economic growth over the 10-15 years, an annual increase of 4-5% in global air transport will result in a doubling of total air transport over this period (Belobaba et al., 2016).

The total global passenger traffic is in an increasing trend over the years, and this increase is expected to continue as presented in Figure 1.1. (ICAO, 2019). In 2019, the total traffic passenger demand increased by 4.2% compared to 2018, and the number of scheduled passengers transported by the airline industry extended to over 4.54 billion passengers.

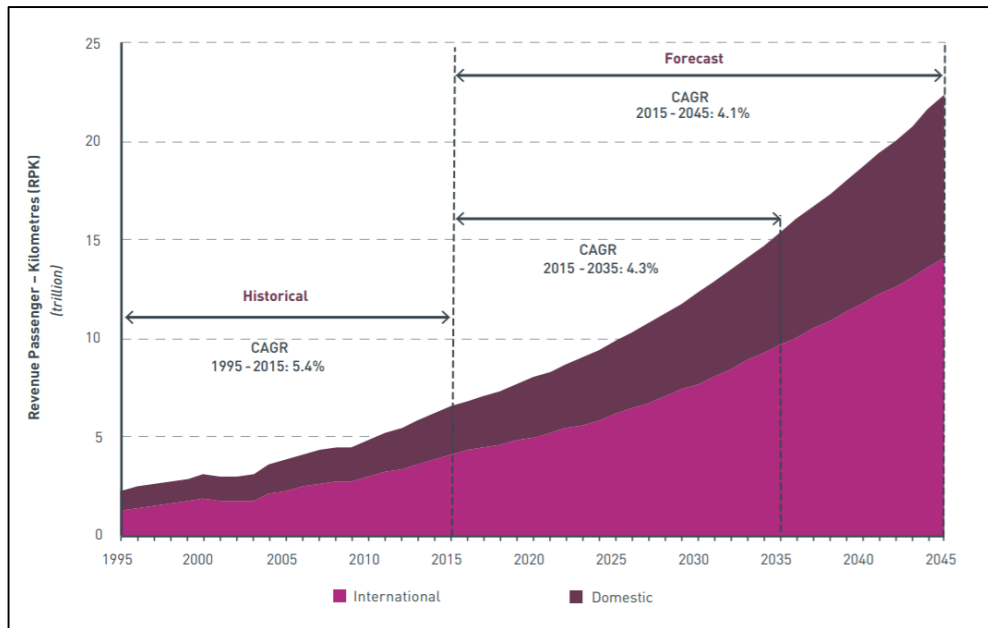


Figure 1.1. Total Passenger Traffic

Source: ICAO, 2019

1.1. Research Problem

It is a fact that the market size of the airline industry is growing with the increase in passenger demand. Also, the number of destinations and airports is increasing depending on the market demand. So, the need to balance the demand-driven capacity increase rises. This capacity would be balanced with expanding the networks of existing airlines and entering new competitors into the global market.

To survive in the competitive aviation industry, airlines should apply the right strategies. At this point, flying to the correct destination would be one of the vital decision problems of an airline that is researched in this study.

1.2. Research Objectives and Research Questions

Whether low-cost carriers, usually fly from point to point, or network carriers, airlines should make their investment decisions based on scientific and analytical decisions when investing in new routes. Otherwise, they may face severe losses in their investments and risk missing out on profitable investments. This decision problem is one of the core decisions of an airline to be profitable and survive in a competitive

market. This study's main aim is to present a guiding model for airline companies that will invest in the opening of new routes. While trying to reach this goal, due to the nature of the problem, the MCDM methods were used.

Respectively, the objectives of this study can be arranged as follows;

- To propose a new hybrid Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS for the airline new route selection problem.
- To develop a model to transfer the decision-makers' and experts' experience from linguistic decisions into a measurable form.
- To evaluate the importance of factors that affect route selection.
- To rank the alternative airline routes.

Accordingly, the problem that airlines have to solve leads us to the following questions;

- What are the key factors that impact airlines' new route selection?
- Do these factors have the same effect or importance?
- Which methods are used for selecting a new airline route?
- How does an airline select a new route?
- How does an airline rank the optimum route between the candidate routes?

1.3. Research Novelty

The novelty of the model proposed in this study depends on the application of a hybrid MCDM model, which combines the Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS methods. The Pythagorean fuzzy numbers, which allow the decision makers to state their choices without restriction and delimitation, are used to evaluate the selection criteria and rank the alternatives. Moreover, there was no research attempt using The Interval-valued Pythagorean Fuzzy AHP combined with Interval-valued Pythagorean Fuzzy WASPAS to solve the route selection problem.

1.4. Research Structure

This study is an application of a hybrid MCDM model, which presents a solution to the airline new route selection problem and consists of five chapters.

Chapter one presents the introduction to the study with a definition of the research problem, the objectives and research questions of the study, and the novelty of the proposed hybrid MCDM method.

Chapter two extends the literature review of the airline's new route selection subject. The first part of the chapter includes the current state-of-the-art research on airline route selection. In the second part, the studies that used MCDM methods, in different fields of the airline industry, are presented. Then, the studies which deal with the route selection problem using MCDM methods are examined. Also, the route selection criteria are summarized.

Chapter three represents the proposed methodology of this study and its application in a full-service network airline in Turkey. First, the fundamentals of the fuzzy method are detailed with the steps of Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS methods. Second, the application of this hybrid method is also elaborated with the pair-wise comparison of route selection criteria and evaluation of five alternative routes regarding the criteria.

Chapter four focuses on the findings of the applied hybrid methodology. The results of applied Interval-valued Pythagorean Fuzzy AHP show the importance and effect of the used criteria on route selection. The Interval-valued Pythagorean Fuzzy WASPAS results give the best of the five alternative routes.

Finally, chapter five concludes the study. Also, this chapter discusses the contribution of this research to the literature and the study's limitations. Eventually, suggestion for future research on the subject is given.

CHAPTER II

LITERATURE REVIEW

In this chapter, firstly, a summarized literature review on researches dealing with airline route selection methodologies is presented. Secondly, some studies that used MCDM techniques in the aviation industry are given. Thirdly, an insight into the studies for airline route selection is listed. Finally, the criteria for new route selection are determined.

2.1. Airline Route Selection Methodologies

Airline route selection is a major part of any airline decision, and is the process of identifying and evaluating the feasibility of new routes.

Previous studies on the subject of airline route selection have used varied methodologies to solve the problem. These studies used publicly available data on market demand, route distance, operating cost, etc., by using the methods such as integer programming, linear programming, and machine learning. All of these studies are focused on forecasting the evolution of the Air Transportation Network (Thekinen et al., 2020).

Linear programming was used by Dantzig (1963), Kushige (1963), and Miller (1967) to deal with the problem. Other methods such as mixed integer programming (De Lamotte and Mathaisel, 1983) and Lagrangian-based algorithms (Balakrishnan et al., 1990) were used in the 1980s.

Besides the conventional constant market share flight schedule, which uses integer or mixed-integer linear programs, Yan et al. (2007) improved a short-term scheduling

model for Taiwan Airlines to enhance the efficiency of fleet routes and flight schedules.

Chang and Lee (2010) used Multi-Objective Goal Programming (MOGP) to determine and select an optimum central airport with its connecting airports. The MOGP model is used to design a point-to-point airline network. The data on the routes between Taipei and Southeast Asia were used in this study.

Ye et al. (2012) examined the findings of analysis between airport-based costs and flight costs by using the discrete event simulation model to select the best strategies for flight plans.

Evans and Schafer (2014) researched the airline route selection problem according to the congestion and the delays which airlines are faced at airports.

Sha et al. (2015) modeled the problem as a linear function of decision. And a binary choice model created from this linear function is used to model the decision of route selection. By using historical datasets, the choices for each variable in the linear function are forecasted. The suggested model provides an estimation of route addition and deletion.

Sha et al. (2016) used discrete choice random-utility theory in order to model the decision of adding or deleting a city-pair route. The study included methods for the explanation of the airline networks, definition of selection sets, and comparison and validation of improved discrete choice models.

Bojia et al. (2016) studied a discrete-event simulation model to evaluate the alternative route selection strategy. The model includes gathered departure/arrival airports, city-pair routes, and other components of the industry. A combination of The Monte Carlo method and the Optimal computing Budget Allocation (OCBA) simulation optimization technique is used to evaluate the performance of several strategies.

Chang et al. (2017) researched the flight routes between Taiwan and the U.S. to determine the most effective routes by using multi-objective programming. This study is also an example of a long-haul route selection model.

Using a data set extracted from the Bureau of Transportation Statistics, Nguyen and Nguyen (2018) utilized logit models to research the relationship between binary variables on the decision of entry or exit and multiple independent variables.

Kong et al. (2019) studied the route selection strategies of full-service and low-cost airlines. The panel-probit model is used to examine the similarities and differences of these airlines. The effects of route characteristics, airport characteristics, characteristics of competing airlines, and the characteristics of airlines on the route selection decision are researched.

Chang et al. (2019) utilized a compromise programming model for selecting direct flight routes to find potential routes for airlines. The selection framework is comprised of the objectives of maximizing total revenue and minimizing total cost with a case study analyzing Taiwan-European region destinations.

By using decision variables such as flight fares, frequency, and aircraft type, Doyme et al. (2019) studied an iterative process to model the competition. They simulated these decision variables by keeping the network structure fixed.

Thekinen et al. (2020) improved a presumable model of an airline route selection problem by using the data from the Bureau of Transportation Statistics.

Birolini et al. (2021) studied on optimization of network planning which consists of route selection, frequencies, and the fleet type of an airline, with the help of an original mixed-integer Non-Convex optimization model.

Ince (2021) researched the data of 617 airlines to examine if there were some rules between the routes of different airlines.

Gaggero and Piazza (2021) studied the subject of route entry by applying multilayer network theory to the airline industry. The study is done in the U.S. domestic market.

Table 2.1. presents a summary of the studies that used methodologies other than MCDM methods.

Table 2.1. Approaches Used for Airline Route Selection

Studies	Approach
Dantzig, Kushige (1963)	Linear Programming
Miller (1967)	Linear Programming
De Lamotte, H., and Mathaisel (1983)	Mixed Integer Programming
Balakrishnan et al. (1990)	Lagrangian-Based Algorithms
Chang and Lee (2010)	Multi-Objective Goal Programming (MOGP)
Ye et al. (2012)	A Discrete Event Simulation Model
Evans and Schäfer (2014)	Investigating Airline Behavior
Sha et al. (2015)	Utility Function (Linear Programming)
Sha et al. (2016)	Discrete Choice Random-Utility Theory
Ye et al. (2016)	A Discrete-Event Simulation Model
Chang et al. (2017)	Multi-Objective Programming
Nguyen and Nguyen (2018)	Logit Models
Kong et al. (2019)	Panel Probit Model with Comparing Low Cost and Full-Service Airlines
Chang et al. (2019)	Comprising Programming Method with Two Objective Functions
Doyme et al. (2019)	Simulation of Decision Variables
Thekinen et al. (2020)	Predictive Model
Birolini et al. (2021)	Mixed-integer Non-Convex Optimization
İnce (2021)	Rules of Destinations
Gaggero and Piazza (2021)	Multilayer Network Theory

2.2. Multi-Criteria Decision-Making Application in Airline Industry

Aviation comes with many alternatives and opposing or incomparable criteria (Dožić, 2019). Therefore, a need for MCDM methods is inevitable. Dožić (2019) also indicated that the usage of fuzzy logic is widespread in the literature of the airline industry because of the necessity of making decisions under uncertainty, incorporating vagueness of human thinking, while considering multi-criteria decision problems. So, there were many important and successful fuzzy logic applications in different fields of the airline industry.

Feng and Wang (2000) used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to evaluate the operational and financial performance of airlines and utilized grey relation analysis.

Tsaura et al. (2002) researched evaluating airline service quality with the help of fuzzy set theory. For weighting the criteria, the Analytical Hierarchy Process (AHP) and for ranking service quality of airlines, TOPSIS are used.

Liou and Chuang (2010) studied an MCDM method for selecting outsourcing providers by using data from Taiwanese airlines. They suggested a hybrid MCDM model that includes of Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, The Analytical Network Process (ANP), and The VIKOR method (ViseKriterijumska Optimizacija I Kompromisno Resenje in Serbian, meaning Multi-criteria Optimization and Compromise Solution). Relations between the criteria are created using DAMATEL, the weights of each criterion are determined with the help of ANP, and finally, the alternatives are prioritized with VIKOR.

Sun et al. (2011) used MCDM methods for aircraft selection problems, considering the robustness of the decision. Three MCDM methods were used to deal with aircraft selection problems, including Elimination and Choice Expressing Reality (ELECTRE), Simple Additive Weighting (SAW), and TOPSIS.

Gomes and Mattos (2014) researched an airline in Brazil that wants to invest in charter flights. They used the multi-criteria decision aiding method of NAIADE (Novel

Approach to Imprecise Assessment and Decision Environments) to evaluate eight alternatives according to eleven criteria.

Dožić and Kalić (2014) used AHP to solve aircraft type selection problems for determined route networks and estimated air transport demand.

Zhang et al. (2015) studied evaluating airline service quality with a non-additive fuzzy measure which is more suitable than conventional additive measures. The study suggests the fuzzy measure and defines the Marichal entropy of the fuzzy measure to find a solution. Also, the aggregator Choquet integral concerning the fuzzy measure is presented. The model is verified with an application of the comprehensive performance of the fifteen U.S. airlines, using data collected over a ten-year period.

Gorener et al. (2017) utilized interval type-2 Fuzzy Analytic Hierarchy Process (FAHP) and interval type-2 fuzzy technique for order preference by similarity to an ideal solution (FTOPSIS) in order to evaluate the supplier performance, and an application is presented to the problem at Turkish Technic Inc.

Su et al. (2018) studied the selection of landing paths for aircraft. A fuzzy selection strategy is suggested to deal with the problem to consider the fuzziness of environmental information and human judgment. The strategy is in view of the idea of Fuzzy Multi-attribute Group Decision Making (FMAGDM).

The above-examined studies that used MCDM methods in different fields of the aviation industry are listed in Table 2.2.

Table 2.2. Studies Used MCDM Methods in Airline Industry

Studies	Objective	Themes	Methods Used
Feng and Wang (2000)	Financial Performance	Evaluation	TOPSIS, GRA
Tsaura et al. (2002)	Service Quality	Evaluation	AHP, TOPSIS, Fuzzy Set Theory
Liou and Chuang (2010)	Ground Handlers	Selection	ANP, DEMATEL, VIKOR, SAW
Sun et al.(2011)	Aircraft	Selection	ELECTRE, SAW, TOPSIS
Dožić and Kalić (2014)	Aircraft	Selection	AHP
Gomes et al. (2014)	Aircraft	Selection	NAIDE, Fuzzy sets
L. Zhang et al. (2015)	Service Quality	Evaluation	Non-additive MCA Method, Choquet integral
Görener et al. (2017)	Supplier Performance	Evaluation	Interval type-2 FAHP, Interval type-2 FTOPSIS
Su et al. (2018)	Landing Path	Selection	FMAGDM, TOPSIS-based, simulation

2.3. MCDM Applications of Airline Route Selection Problem

Janic and Reggiani (2002) used the combination of three MCDM methods for the new hub airport selection decision for an airline. The three MCDM methods were SAW, TOPSIS, and AHP, and applied to a preselected set of alternative airports.

Lu and Liu (2014) proposed an AHP framework for Taiwanese airlines. The determinants of potential service expansion are evaluated with a market opportunity analysis (MOA). The relative weights among these determinants are measured with a novel rank pair-wise comparison (RPC), and Grey Relational Analysis (GRA) is used to evaluate twelve airports in China.

Chen et al. (2014) combined FTOPSIS and multichoice goal programming (MCGP) to solve the location selection of logistic centers to find an appropriate logistic center by comparing alternative locations for the airline industry.

Borkar et al. (2016) used some multi-attribute decision-making (MADM) methodologies such as SAW, WPM, AHP, and TOPSIS methods for selecting the optimal routes.

Prasad and Raj (2017) have implemented the AHP method for determining the best destination for Nepal Airlines.

Deveci et al. (2017) utilized type-1 and type-2 fuzzy TOPSIS methods to evaluate potential routes for an airline in Türkiye. They evaluate some destinations in the North American region according to the eleven criteria.

Yılmaz et al. (2018) used the AHP method to select an optimal route for flights performed by small Greek airlines to Eskisehir Airport in Türkiye.

Zhang et al. (2018) studied the multi-airport system (MAS) in China. An improved TOPSIS method was suggested to notice the coordinated development of regional airports. The study put forward an index system, and the Beijing capital airport air route is evaluated considering the development of the Beijing-Tianjin-Hebei regional MAS.

Yu and Liu (2019) used fuzzy MCDM to solve the route selection problem by converting the linguistic language and choice information into trapezoidal fuzzy numbers with the given fuzzy language. The weight of each criterion in the route selection problem is determined using a programming model in which the total deviation between trapezoidal fuzzy numbers is minimized.

Loh et al. (2020) studied to determine and degree the airport selection criteria of Low-Cost Carriers. In the research, the collected data was analyzed using FAHP.

Aydın and Seker (2020) researched a hub selection problem for a Low-Cost Carrier. MCDM methods were applied to identify a new hub airport. An Interval-valued intuitionistic fuzzy (IVIF) set based on weighted aggregated sum product assessment (WASPAS) and multi-objective optimization by ratio analysis (MULTIMOORA) methods were improved for the selection process.

Rolka et al. (2020) presented a hybrid logical-arithmetic model for selecting flight routes. A hybrid MCDM model was conducted, including numerical and additional

linguistic criteria. These criteria were converted into a crisp decision matrix for finding the final ranking with the help of the TOPSIS method.

Table 2.3. summarized the MCDM methods used for airline route selection problems.

Table 2.3. Studies Used MCDM Methods in Airline Route Selection

Studies	Objective	Methods Used
Janic and Reggiani (2002)	Hub Selection	SAW, TOPSIS, AHP
Lu and Liu (2014)	Route Selection	AHP, Market Opportunity Analysis, GRA
Chen et al. (2014)	Logistic Center Selection	FTOPSIS, MCGP
Borkar et al. (2016)	Route Selection	SAW, WPM, AHP, TOPSIS
Prasad and Raj (2017)	Route Selection	AHP
Deveci et al. (2017)	Route Selection	Interval-1 Interval-2 FTOPSIS
Kucuk Yilmaz et al. (2018)	Route Selection	AHP
J. Zhang et al. (2018)	Airport Selection	TOPSIS
Yu and Liu (2019)	Route Selection	Trapezoidal Fuzzy Numbers
Loh et al. (2020)	Airport Selection	FAHP
Aydin and Seker (2020)	Hub Selection	WASPAS, MULTIMOORA
Rolka et al. (2020)	Flight Route Selection	TOPSIS

2.4. Selection Criteria for Evaluating A New Route

Based on the literature review, many criteria are considered during the route selection problem. The selection criteria used in this study are shown in Figure 2.1.

The main selection criteria are shown as c_i , where i is the number of relevant main criteria, and sub-criteria are shown as c_{ij} , where j is the number of the sub-criterion belonging to i^{th} main criterion.

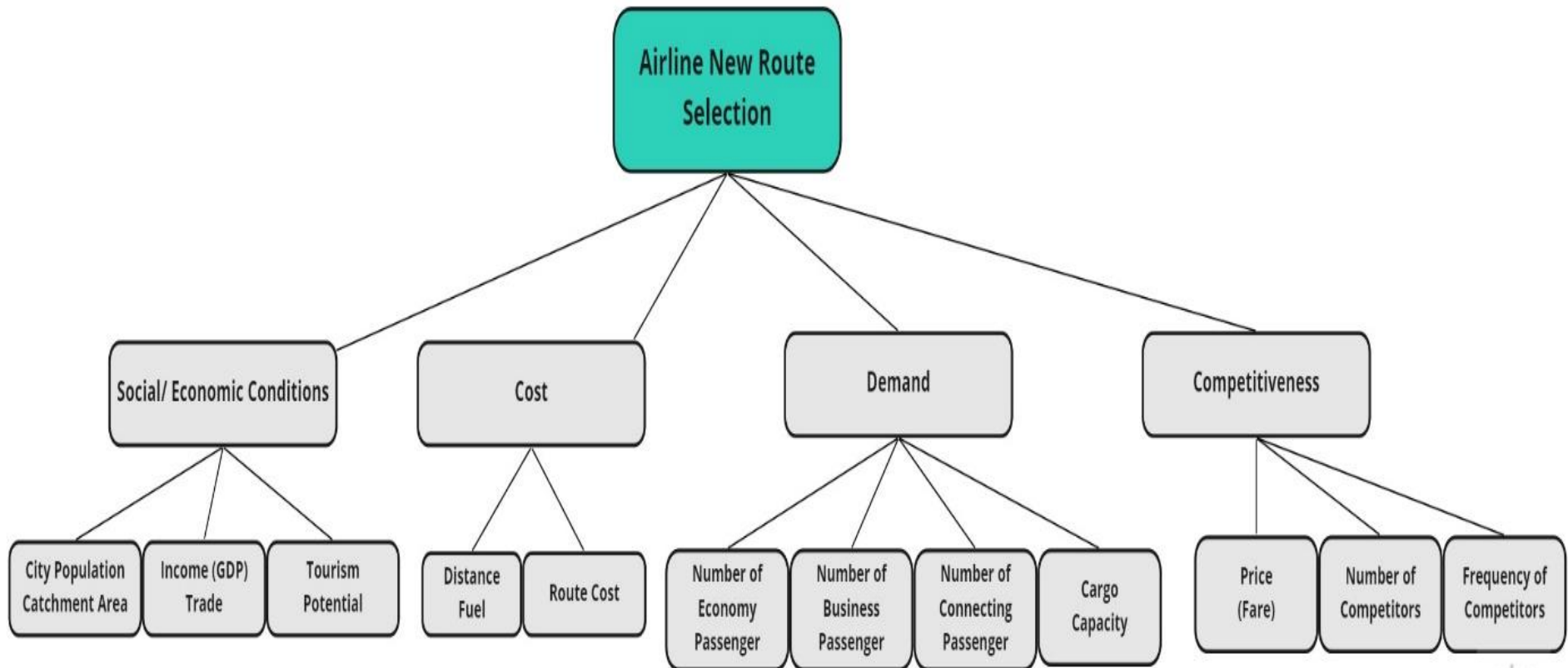


Figure 2.1. Criteria Used for Route Selection

The selected twelve criteria are described as follows;

C₁, Social / Economic Conditions: This main criterion consists of the social and economic conditions of the destination region.

C₁₁, City Population: The sub-criterion is one of the social parameters for a new route. The catchment areas will give information about estimated demand.

C₁₂, Income (GDP) and Trade: Income and GDP indicate the purchasing power of the destination city. It is also an economic measure that determines the growth of the country.

C₁₃, Tourism Potential: A high tourism potential for a destination point is an advantage for airlines. This sub-criterion makes the destination attractive for passengers.

C₂, Cost: The total cost of the route is including expenses such as fuel, crew, airport charges, maintenance, handling, and others.

*C₂₁, Distance*Fuel:* The distance of a route is regarding the cost of fuel consumption which has the most significant share in the cost structure.

C₂₂, Route Cost: Except for fuel consumption, airport charges, maintenance, and staff expenses have an important impact on the profitability of the destination route.

C₃, Demand: This main criterion indicates the total passenger demand to/from the destination.

C₃₁, Number of Economy Passengers: These passengers fly for leisure purposes, and with optimum revenue management, an airline can get considerable revenue.

C₃₂, Number of Business Passengers: Business passengers impact revenue of the route with a noticeable effect that they are valuable passengers for an airline.

C₃₃, Number of Connecting Passengers: This kind of passenger flies from one point to another with a connecting flight.

C₃₄, Cargo Capacity: This criterion indicates the amount of cargo that flows from/to the destination point of the route.

C₄, Competitiveness: This criterion indicates the existence of competitors on the same route.

C₄₁, Price (Fare): This sub-criterion indicates the average ticket fare of the route in which other competitors operate.

C₄₂, Number of Competitors: The number of airlines that operates flight to this destination.

C₄₃, Frequency of Competitors: This sub-criterion indicates the number of daily and weekly flights of other airlines which operates at this destination.

Table 2.4. presents these criteria and the studies which used them in the literature.

Table 2.4. Criteria Used for Route Selection

Studies	Criteria Used											
	<i>C₁₁</i>	<i>C₁₂</i>	<i>C₁₃</i>	<i>C₂₁</i>	<i>C₂₂</i>	<i>C₃₁</i>	<i>C₃₂</i>	<i>C₃₃</i>	<i>C₃₄</i>	<i>C₄₁</i>	<i>C₄₂</i>	<i>C₄₃</i>
Gaggero and Piazza (2021)	√	√		√						√		
Birolini et al. (2021)	√	√		√		√	√			√		√
Aydin and Seker (2020)	√	√		√		√	√					
Thekinen et al. (2020)				√	√	√	√	√				
Loh et al. (2020)	√				√							
Chang et al. (2019)					√	√	√	√		√		√
Kong et al. (2019)			√	√		√	√	√			√	
Yu and Liu (2019)					√	√	√	√		√	√	√
J. Zhang et al. (2018)						√	√	√			√	
Kucuk Yilmaz et al. (2018)	√	√	√		√							
Deveci et al. (2017)	√	√	√	√	√	√	√	√			√	√
Chang et al. (2017)					√	√	√	√		√		√
Sha et al. (2016)				√	√	√	√	√				
Lu and Liu (2014)	√	√	√							√	√	√
Janic and Reggiani (2002)	√	√			√							

CHAPTER III

METHODOLOGY & APPLICATION

This chapter discusses the details of the methodology of the integration model between Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS for airline new route selection under the MCDM environment and the application of the proposed model in a full-service network airline.

In this study, Pythagorean fuzzy numbers are utilized in the process of weighting evaluation criteria, as human thinking and judgments are imprecise, uncertainty, and ill-defined. Pythagorean fuzzy number incorporated with AHP is more relevant as compared to the classical AHP. Subsequently, alternative airline routes are ranked using Pythagorean Fuzzy WASPAS, which includes two MCDM methods, Weighted Sum Model (WSM) and Weighted Product Model (WPM).

The fuzzy set theory was introduced by Zadeh (1965) in order to overcome the vagueness of human judgment. One of the main contributions of fuzzy set theory is having the capability of representing vague knowledge. It also lets mathematical operators and programming apply to the fuzzy domain. When a specific subject is complicated and accurate information about this subject is absent, we are forced to consider people's judgment and ideas. In these situations, fuzzy sets theory becomes a powerful tool that represents the view of an expert in a better way. The Traditional AHP does not consider the uncertainty related to mapping one's judgment to a number. And the subjective judgments of decision makers or the preferences of decision-makers have a strong influence on the AHP, whereas fuzzy sets theory could deal with these deficiencies of AHP. Because of this advantage, an integration of AHP with the fuzzy set theory known as fuzzy AHP (FAHP), is used with Pythagorean fuzzy numbers.

3.1. Methodological Framework

The framework of this study is depicted in Figure 3.1.

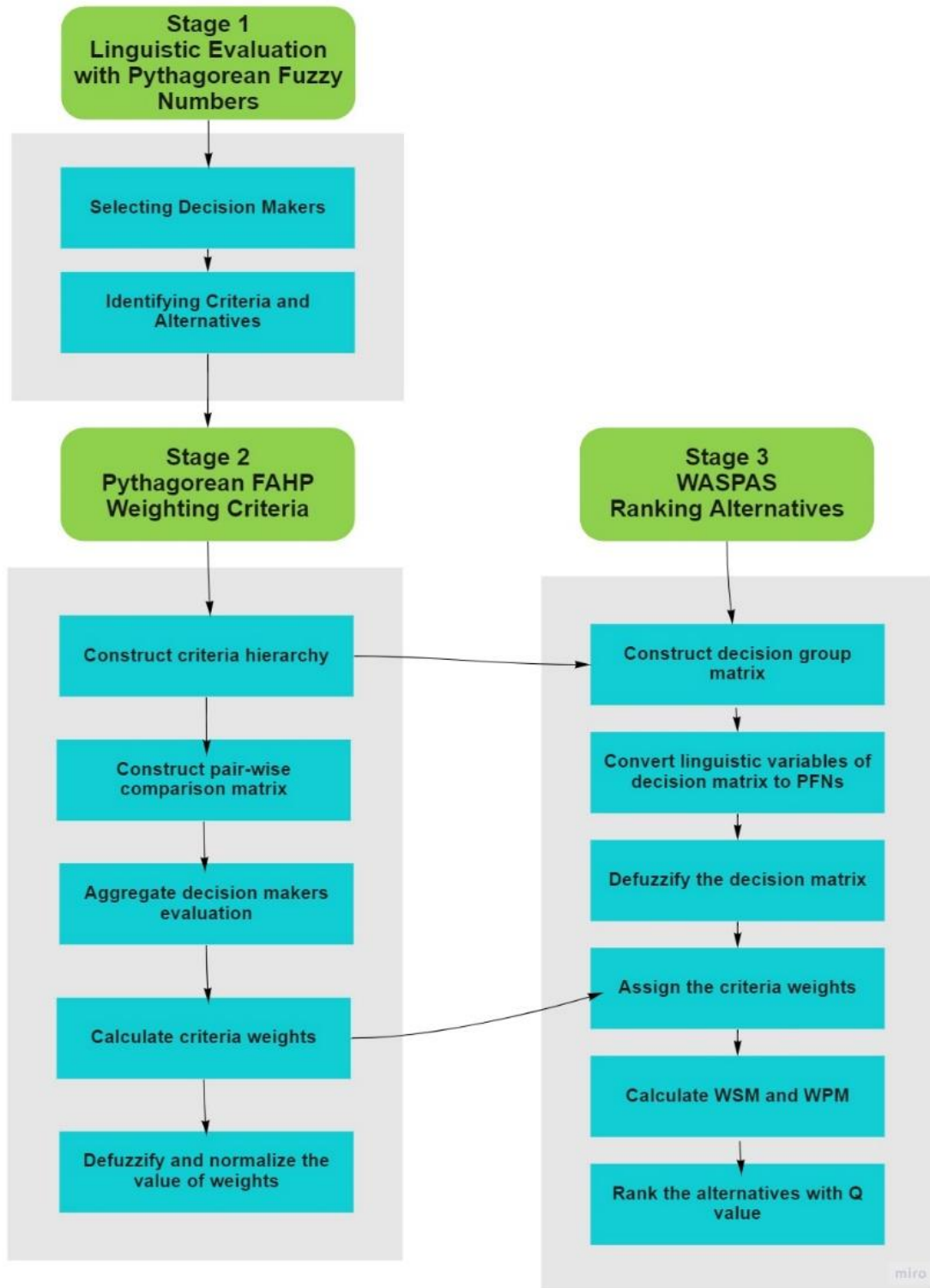


Figure 3.1. Design of the Proposed Method

The first activity is to identify the problem. Then with the help of experts or decision makers, criteria and alternatives are evaluated to solve the problem. In this work, Interval-valued Pythagorean Fuzzy AHP is used for weighting the selection criteria, and Interval-valued Pythagorean Fuzzy WASPAS is used for ranking alternatives by evaluating the weighted criteria.

3.2. Fuzzy Sets

In this section, the Pythagorean fuzzy set (PFS) is introduced. Before that, the Intuitionistic Fuzzy Set (IFS) is firstly summarized since the PFS is a generalization of IFS.

3.2.1. Intuitionistic Fuzzy Sets (IFS)

DEFINITION 3.1. Let a set X be a universe of discourse. An IFS I is expressed as follows;

$$I = \{ \langle x, I(\mu(x), \nu(x)) \rangle \mid x \in X \} \quad (3.1)$$

$$0 \leq \mu(x) + \nu(x) \leq 1 \quad \forall x \in X \quad (3.2)$$

$\mu_I: X \rightarrow [0,1]$ defines the degree of membership of the element $x \in X$ to I ,

$\nu_I: X \rightarrow [0,1]$ defines the degree of non-membership of the element $x \in X$ to I ,

$\pi_I(x) = 1 - \mu_I(x) - \nu_I(x)$ is called the degree of indeterminacy of $x \in X$ to I .

Furthermore, $\alpha = I(\mu_\alpha, \nu_\alpha)$ is an intuitionistic fuzzy number (IFN), where μ_α and ν_α are the degree of membership and the degree of non-membership of the element $x \in X$ to I , respectively.

The primary operational rules of the IFNs $\alpha_j = I(\mu_{\alpha_j}, \nu_{\alpha_j})$ ($j = 1, 2$) and $I(\mu_{\alpha}, \nu_{\alpha})$, are presented as follows (Xu, 2007; Xu & Yager, 2006):

- $\alpha_1 \oplus \alpha_2 = I(\mu_{\alpha_1} + \mu_{\alpha_2} - \mu_{\alpha_1} \mu_{\alpha_2}, \nu_{\alpha_1} \nu_{\alpha_2})$;
- $\alpha_1 \otimes \alpha_2 = I(\mu_{\alpha_1} \mu_{\alpha_2}, \nu_{\alpha_1} + \nu_{\alpha_2} - \nu_{\alpha_1} \nu_{\alpha_2})$;
- $\lambda \alpha = I(1 - (1 - \mu_{\alpha})^{\lambda}, \nu_{\alpha}^{\lambda}), \lambda > 0$;
- $\alpha \lambda = I(\mu_{\alpha}^{\lambda} - (1 - \nu_{\alpha})^{\lambda}), \lambda > 0$;
- $\alpha^c = I(\nu_{\alpha}, \mu_{\alpha})$

But, in some MCDM issues, the decision-maker's evaluation does not support Equation 3.2. Namely, the sum of membership degrees and non-membership degrees can be more than 1 in certain decision situations. This state cannot be expressed by using the IFS.

Thus, Yager improved a novel model of PFS to cover this state and to prevent decision-makers from changing their preferences to fit within IFS's restraints (X. Zhang & Xu, 2014).

3.2.2. Pythagorean Fuzzy Sets (PFS)

In the Pythagorean fuzzy set, the sum of the membership and non-membership degree can exceed 1, but the sum of squares cannot.

DEFINITION 3.2. Let a set X be a universe of discourse. A PFS P is expressed as follows;

$$P = \{ (x, \mu^P(x), \nu^P(x)); x \in X \}, \quad (3.3)$$

$$0 \leq (\mu^P(x))^2 + (\nu^P(x))^2 \leq 1, \quad \forall x \in X \quad (3.4)$$

$\mu_P: X \rightarrow [0, 1]$ describes the degree of membership of the element $x \in X$ to P ,

$\nu_P: X \rightarrow [0, 1]$ describes the degree of non-membership of the element $x \in X$ to P ,

$\pi_P(x) = \sqrt{\{1 - \mu_P^2(x) - \nu_P^2(x)\}}$ is called the degree of indeterminacy of $x \in X$, to P .

Simply, $(\mu_P(x), \nu_P(x))$ is called a Pythagorean fuzzy number (PFN) indicated by

$\beta = P(\mu_\beta, \nu_\beta)$, where $\mu_\beta, \nu_\beta \in [0, 1]$, $\pi_\beta = 1 - (\mu_\beta)^2 - (\nu_\beta)^2$, and $(\mu_\beta)^2 + (\nu_\beta)^2 \leq 1$.

Yager (2013), Yager (2014), and (Yager & Abbasov, 2013) demonstrated the major operations on PFNs as follows;

- $\beta_1 \cup \beta_2 = P(\max\{\mu_{\beta_1}, \mu_{\beta_2}\}, \min\{\nu_{\beta_1}, \nu_{\beta_2}\})$
- $\beta_1 \cap \beta_2 = P(\min\{\mu_{\beta_1}, \mu_{\beta_2}\}, \max\{\nu_{\beta_1}, \nu_{\beta_2}\})$
- $\beta^c = P(\nu_\beta, \mu_\beta)$

where, $\beta_1 = P(\mu_{\beta_1}, \nu_{\beta_1})$, $\beta_2 = P(\mu_{\beta_2}, \nu_{\beta_2})$ and $\beta = P(\mu_\beta, \nu_\beta)$ are PNS.

Zhang and Xu (2014) improved some operations on the base of a relationship between PFNs and IFNs as follows;

- $\beta_1 \oplus \beta_2 = P(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2 \mu_{\beta_2}^2}, \nu_{\beta_1} \nu_{\beta_2})$
- $\beta_1 \otimes \beta_2 = P(\mu_{\beta_1} \mu_{\beta_2}, \sqrt{\nu_{\beta_1}^2 + \nu_{\beta_2}^2 - \nu_{\beta_1}^2 \nu_{\beta_2}^2})$
- $\lambda \beta = P(\sqrt{1 - (1 - \mu_\beta^2)^\lambda}, (\nu_\beta)^\lambda), \lambda > 0$
- $\beta \lambda = P((\mu_\beta)^\lambda, \sqrt{1 - (1 - \nu_\beta^2)^\lambda}), \lambda > 0$

For PFNs $\beta_1 = P(u_{\beta_1}, v_{\beta_1})$, $\beta_2 = P(u_{\beta_2}, v_{\beta_2})$, and $\beta = P(u_{\beta}, v_{\beta})$, following rules are given;

- $\beta_1 \oplus \beta_2 = \beta_2 \oplus \beta_1$
- $\beta_1 \otimes \beta_2 = \beta_2 \otimes \beta_1$
- $\lambda(\beta_1 + \beta_2) = \lambda\beta_1 \oplus \lambda\beta_2, \lambda > 0$ $\lambda(\beta_1 + \beta_2) = \lambda\beta_1 \oplus \lambda\beta_2, \lambda > 0.$
- $\lambda_1\beta \oplus \lambda_2\beta = (\lambda_1 + \lambda_2)\beta, \lambda_1, \lambda_2 > 0$
- $(\beta_1 \otimes \beta_2)^\lambda = \beta_1^\lambda \otimes \beta_2^\lambda, \lambda > 0$
- $\beta^{\lambda_1} \otimes \beta^{\lambda_2} = \beta^{(\lambda_1 + \lambda_2)}, \lambda_1, \lambda_2 > 0$

DEFINITION 3.3. Let $\beta_j = P(u_{\beta_j}, v_{\beta_j})$ ($j = 1, 2$); then $\beta_1 \geq \beta_2$ if and only if $u_{\beta_1} \geq u_{\beta_2}$ and $v_{\beta_1} \leq v_{\beta_2}$.

DEFINITION 3.4. Let $\beta = P(u_{\beta}, v_{\beta})$ be a PFN; the score function of β is presented as follows;

$$s(\beta) = (u_{\beta})^2 - (v_{\beta})^2, \quad (3.5)$$

The score function $s(\beta)$ consists of some rules as follows;

- For any PFN $\beta = P(u_{\beta}, v_{\beta})$, the proposed score function $(\beta) \in [-1, 1]$.
- For two PFNs $\beta_j = P(u_{\beta_j}, v_{\beta_j})$ ($j = 1, 2$), if $\beta_1 \leq \beta_2$, then $s(\beta_1) \leq s(\beta_2)$.

DEFINITION 3.5. Let $\beta_j = P(u_{\beta_j}, v_{\beta_j})$ ($j = 1, 2$) be two PFNs, $s(\beta_1)$ and $s(\beta_2)$ be the scores of β_1 and β_2 , respectively; then

- If $s(\beta_1) < s(\beta_2)$, then $\beta_1 < \beta_2$;
- If $s(\beta_1) > s(\beta_2)$, then $\beta_1 > \beta_2$;
- If $s(\beta_1) = s(\beta_2)$, then $\beta_1 \sim \beta_2$;

Moreover, Yager (2014) presented the next weighted averaging aggregation operator in order to aggregate PFNs.

DEFINITION 3.6. The function of PFWA, which is called PFWA, is presented as follows;

Pythagorean fuzzy weighted averaging (*PFWA*): $\Theta^n \rightarrow \Theta$ if

$$PFWA(\beta_1, \beta_2, \dots, \beta_n) = P(\sum_{j=1}^n w_j u_{\beta_j}, \sum_{j=1}^n w_j v_{\beta_j}) \quad 3.6$$

$\beta_j = P(u_{\beta_j}, v_{\beta_j})$ ($j = 1, 2, \dots, n$) be a collection of PFNs,

$w = (w_1, w_2, \dots, w_n)$ be the weight vector of β_j ($j = 1, 2, \dots, n$),

w_j specifies the magnitude degree of β_j ,

$w_j \geq 0$ ($j = 1, 2, \dots, n$) $\sum_{j=1}^n w_j = 1$.

3.2.3. The Preference for Pythagorean Fuzzy Numbers

As we mentioned, the Pythagorean Fuzzy Numbers are a generalization of Intuitionistic Fuzzy Numbers. They offer more flexibility in the manifestation of uncertainty. The advantages in presenting the degrees of membership degree and non-membership hesitancy are essentially due to expanding the area for setting such value.

In real life, the decision-makers preferences may not be satisfied with the condition of Intuitionistic Fuzzy Sets that the sum of membership and non-membership degrees should be less than or equal to 1. On the other side, in the Pythagorean fuzzy set, the sum of the membership and non-membership degree can exceed 1. However, Pythagorean Fuzzy Sets also sustain the advantages of membership (μ) and non-membership (v) functions.

The value range of membership function and non-membership function are expanded from triangle to quarter circle as presented in Figure 3.2. This expansion of the value area makes the amount of information of PFSs expand 1.57 times that of the IFSs. And still, it ensures that IFSs are all PFSs. (Fan et al., 2022).

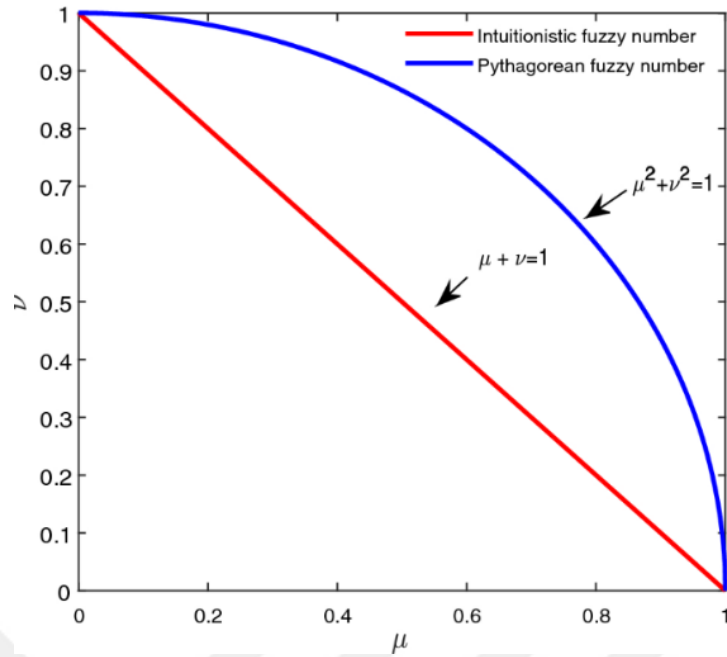


Figure 3. 2. The Comparison of IFNs Space and PFNs Space

Source: Akram et al., 2019

In other words, the PFS maintains a larger preference area for decision-makers to express their opinions.

We can say that in real-world situations where it is necessary to make a preference under uncertainty, PFSs have a higher potential in dealing with vague and imperfect information when compared to IFNs. They can be used to characterize the uncertainty more sufficiently and precisely.

Therefore, in this study, Interval-valued Pythagorean Fuzzy Numbers are used to deal with the vagueness of the decision-maker's opinions.

3.3. Interval-Valued Pythagorean Fuzzy AHP

After selecting the experts and identifying the selection criteria in the first stage of the proposed model, the next step is to determine the importance level of the criteria. In this section, based on the definitions described in the previous sections, the steps of Interval-valued Pythagorean Fuzzy AHP are shown as follows;

Step 1: The compromised pair-wise comparison matrices of main criteria and sub-criteria in the form of $A = (a_{ik})_{m \times m}$ are created regarding the linguistic evaluations of decision makers using the scale in Table 3.1., proposed by (Ilbahar et al., 2018).

Table 3.1. Linguistic Scale for Interval-Valued Pythagorean FAHP (Ilbahar et al., 2018)

Linguistic Terms	PFN equivalents IVPF numbers			
	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_U
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

Step 2: The difference matrices $D = (d_{ik})_{m \times m}$ between the lower and upper values of the membership and non-membership functions are determined using the following equations;

$$d_{ikl} = \mu_{ikL}^2 - \nu_{ikU}^2, \quad (3.7)$$

$$d_{ikl} = \mu_{ikU}^2 - \nu_{ikL}^2, \quad (3.8)$$

Step 3: Interval multiplicative matrices $S = (s_{ik})_{m \times m}$ is calculated using the following equations;

$$S_{ik_L} = \sqrt{1000^{d_{ik_L}}} , \quad (3.9)$$

$$S_{ik_U} = \sqrt{1000^{d_{ik_U}}} , \quad (3.10)$$

Step 4: The determinacy value $\tau = (\tau_{ik})_{m \times m}$ is determined by using the following equations;

$$\tau_{ik} = 1 - (\mu_{ik_U}^2 - \mu_{ik_L}^2) - (v_{ik_U}^2 - v_{ik_L}^2) , \quad (3.11)$$

Step 5: The determinacy degrees are multiplied with $S = (s_{ik})_{m \times m}$ matrix for obtaining the matrix of weights $T = (t_{ik})_{m \times m}$ before normalization using the following equations;

$$t_{ik} = \left(\frac{S_{ik_L} + S_{ik_U}}{2} \right) \tau_{ik} , \quad (3.12)$$

Step 6: Each normalized priority weight w_i is calculated by using the following equations;

$$\omega_{ik} = \left(\frac{\sum_{k=1}^m t_{ik}}{\sum_{i=1}^m \sum_{k=1}^m t_{ik}} \right) , \quad (3.13)$$

3.4. Interval-Valued Pythagorean Fuzzy WASPAS Method

The last stage of the proposed methodology is to evaluate alternatives according to the criteria by using the Pythagorean Fuzzy WASPAS method. In this section, the steps of the Interval-valued Pythagorean Fuzzy WASPAS method are introduced using the linguistic scale of PFNs.

WASPAS method was developed by Zavadskas et al. (2012) and integrates two MCDM methods of WSM and WPM. The ranking of alternatives depends on the results of both WSM and WPM. And it is the most applicable MCDM which considers verification of the accuracy by combining these two MCDM methods. The features of the WASPAS method are presented as follows;

- It can be considered a compensatory method because of including two MCDM methods,
- The criteria are independent,
- The qualitative evaluations are transferred into quantitative assessments.

Before applying the method, it is necessary to perform a decision/evaluation matrix in the form of $X = [x_{ij}]_{m \times n}$ where x_{ij} is the performance value of the i th alternative with respect to the j th criterion. Here, m is the number of alternatives, and n is the number of criteria. The decision matrix consists of linguistic evaluations of the experts, as given in Table 3.2. Then, linguistic variables are transformed into the corresponding Interval-Valued PFNs.

Table 3.2. Linguistic Terms for Evaluating Alternatives

Linguistic term	Abbreviation	Interval-valued Pythagorean fuzzy number
Extremely Good	EG	([0.8,0.9], [0.1,0.2])
Very Good	VG	([0.7,0.8], [0.2,0.3])
Good	G	([0.6,0.7], [0.3,0.4])
Fair	F	([0.5,0.6], [0.4,0.5])
Poor	P	([0.3,0.4], [0.6,0.7])
Very Poor	VP	([0.2,0.3], [0.7,0.8])
Extremely Poor	EP	([0.1,0.2], [0.8,0.9])

WASPAS method's application steps can be summarized as follows (Chakraborty & Zavadskas, 2014);

Step 1 (The Normalized Decision Matrix): The evaluation matrix is normalized using the following Equation 3.14 to make the values of the matrix comparable.

$$X_{ij} = \begin{cases} \frac{x_{ij}}{\max x_{ij}}, & \text{if } j \in C_b \\ \frac{\min x_{ij}}{x_{ij}}, & \text{if } j \in C_c \end{cases} \quad (3.14)$$

where X_{ij} indicates the normalized value of the decision matrix of the i th alternative with respect to the j th criteria.

Step 2 (Weighted Sum Model): (WSM (Q_i^1)) Apply the following equation in order to calculate the additive relative importance value of each alternative.

$$Q_i^1 = \sum_{j=1}^n w_j x_{ij} \quad (3.15)$$

where w_j indicates the weight of criteria (w_1, w_2, \dots, w_n) and Q_i^1 indicates the WSM value of the i th alternative.

Step 3 (Weighted Product Model): (WPM (Q_i^2)) Apply Equation 3.16 to calculate the multiplicative relative importance value of each alternative.

$$Q_i^2 = \prod_{j=1}^n (x_{ij})^{w_j} \quad (3.16)$$

where Q_i^2 indicates the WPM value of the i th alternative.

Step 4 (The Joint Generalized Criterion): (Q_i) The joint generalized criterion (Q_i) value of each alternative is calculated by the following equation;

$$Q_i = \lambda Q_i^1 + (1 - \lambda) Q_i^2 \quad (3.17)$$

where λ is called the parameter of the WASPAS method. The value of λ is between 0 and 1. When $\lambda=1$, the WASPAS method is closer to WSM, and when $\lambda=0$, it transforms to the WPM model.

Step 5 (The final Ranking of Alternatives): Considering the joint generalized criterion (Q_i) values of each alternative, rank them in decreasing order.

3.5. Application of Proposed Method to Airline Route Selection Problem

In this part, the proposed model is applied to the route selection problem of a full-service network airline company in Türkiye which has a wide range of flight networks.

3.5.1. Selecting Criteria and Alternative Routes

In the first stage of the method, the selection criteria and the alternative destinations are identified, and the expert decision makers (DM) are selected. The new route selection or route development process is driven by the network development/planning department of an airline. The experts whose opinions are consulted in this study are employed in the network development department of an airline, and all of the decision-makers have at least five years of expertise. Firstly, the first expert group, which consists of nine decision-makers (From DM₁ to DM₉), has been established. The questionnaire, shown in Appendix A Table A.1, is applied to these decision-makers to evaluate the weighting value of each twelve criteria in Figure 3.2. Also, by the help of the initial expert team, the five alternative routes are determined. Secondly, another set of five decision-makers (from EDM₁ to EDM₅) has been arranged, and they were asked to evaluate five alternative routes with respect to the selection criteria. The hierarchical design of the decision-making problem is shown in Figure 3.3.

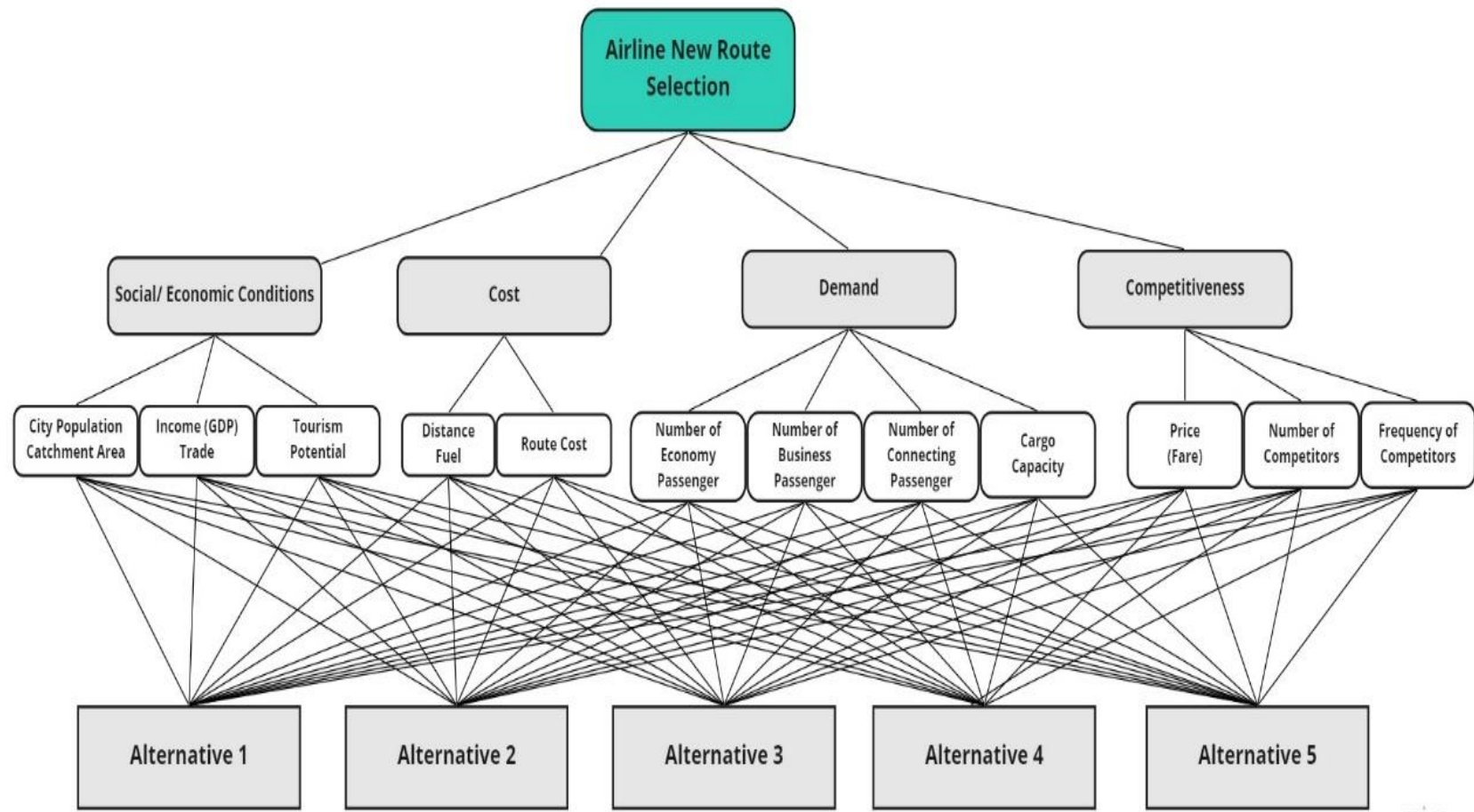


Figure 3.3. The Hierarchy of Route Selection Problem

As depicted in Figure 3.3, twelve criteria under the four main criteria are employed for the new route selection decision, and their definitions are presented in Table 3.3.

Table 3.3. Evaluation Criteria and Descriptions

Criteria	Definition
<i>C₁, Social /Economic Conditions</i>	It consists of the social and economic conditions of the destination region.
<i>C₁₁, City Population</i>	This criterion is one of the socio-demographic parameters for a new route. The catchment areas will give information about estimated demand.
<i>C₁₂, Income (GDP) and Trade</i>	Income and GDP indicate the purchasing power of the destination city. It is also an economic measure that determines the growth of the county.
<i>C₁₃, Tourism Potential</i>	The high tourism potential of destination points creates an advantage for airlines.
<i>C₂, Cost</i>	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
<i>C₂₁, Distance*Fuel</i>	The distance to a destination and the fuel consumption has the biggest share in the cost structure of aviation operations.
<i>C₂₂, Route Cost</i>	Except for fuel consumption, airport charges, maintenance, and staff expenses are essential.
<i>C₃, Demand</i>	This main criterion indicates the total passenger demand from/to the destination.
<i>C₃₁, Number of Economy Passengers</i>	These passengers fly for leisure purposes.
<i>C₃₂, Number of Business Passengers</i>	These passengers fly for business purposes.
<i>C₃₃, Number of Connecting Passengers</i>	These passengers fly via a connecting flight.
<i>C₃₄, Cargo Capacity</i>	Amount of the cargo flow from/to the region of destination.
<i>C₄, Competitiveness Index</i>	There are other competitor airlines on the route.
<i>C₄₁, Price (Fare)</i>	The average ticket price of competitor airlines.
<i>C₄₂, Number of Competitors</i>	The Number of competitor airlines.
<i>C₄₃, Frequency of Competitors</i>	The flight number of competitor airlines.

The five alternative routes, which are selected with the help of the first group of decision-makers, are shown in Figure 3.4.



Figure 3.4. The Five Alternative Routes

Source: GreatCircleMap, 2022

Alternative 1 (SEA): Seattle is one of the important airports in North America, hosting 36,2 million passengers in 2021, which is down 30% from 2019. SEA sets a record for air cargo tonnage, both domestic and international, with 498.741 metric tons of air cargo in 2021. Currently, there are 113 connections from SEA to 91 domestic and 22 international cities with 30 airlines (Port of Seattle, 2022).

Although the population of the city was 787.995 in 2020, the metropolitan area has more than 3,5 million. This makes it the 15th largest metro area in the country.

Alaska Airlines and Delta Airlines are the two dominant airlines operating in SEA. They have a 70 % market share of the SEA, where Alaska is the leading domestic service with 52,1%, and Delta dominates international service with 31,3% market share (Magazine,S.B., 2022).

Alternative 2 (DFW): DFW, with 135 direct domestic routes and 40 direct international routes hosts 60 million passengers each year. The DFW airport's catchment area has a 6,4 million population (TheRouteShop, 2022-a).

It is one of the most significant airports in North America for passengers transiting to other regions. It transfers about 600.000 passengers including over 155.00, to/from Middle East Region. These connecting flights are shared by long-haul airlines,

including Qatar and Emirates. DFW also has a demand in eastern regions, including central Asia and India (SimpleFlying, 2021-b).

On the other hand, it is the hub airport of American Airlines, one of the major airlines in the region. American Airlines has a joint venture with British Airlines. Furthermore, with one million international transported cargo in 2021, its network extends to the Middle East, Europe, and South America (AirCargoNews, 2022).

Alternative 3 (DEN): DEN, with 189 domestic routes and 26 international routes to 12 countries, hosted 69 million passengers in 2019 and 33,7 million passengers in 2020. Because of its location, it benefits from point-to-point flights. 36% of the passengers were connecting in 2019, whereas this rate increased to %40 in 2020. Also, it handled 3,2 million international passengers in 2019, which was 4,6 % of its total passenger traffic 2019 (SimpleFlying, 2021-a). Lastly, the monthly flight traffic in DEN reached 59,5 thousand in May 2022 (DenverAirport, 2022).

All major airlines, among which United has the biggest share, followed by Southwest Airlines, and Frontier Airlines, serve in this airport. With a 5 million population, it has a notable catchment area. In 2020, 146.444 tons of cargo were transported via this airport (TheRouteShop, 2022-b).

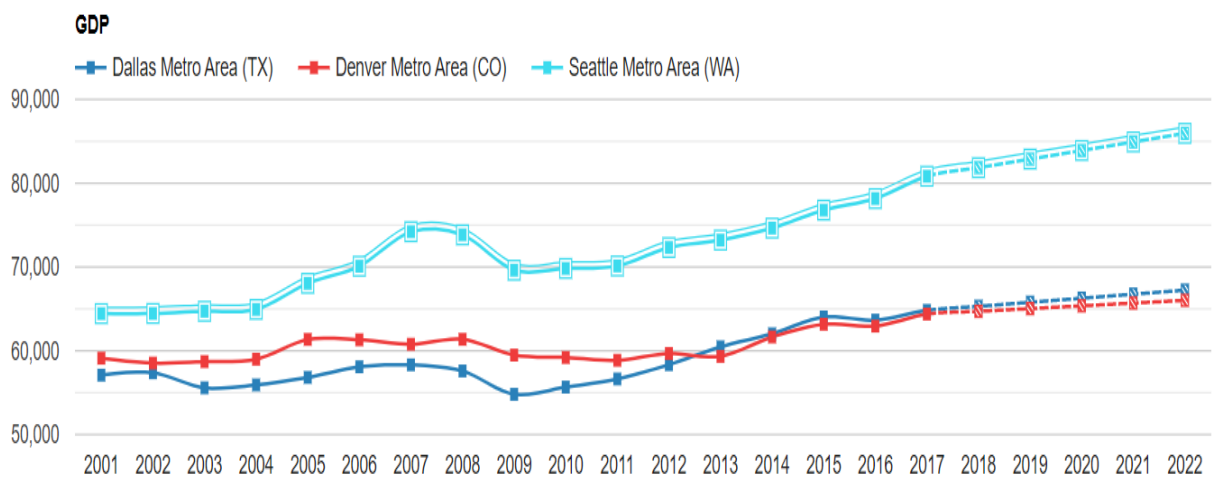


Figure 3.5. The Annual Change in GDP for SEA, DFW, and DEN

Source: OpenDataNetwork, 2022

Alternative 4 (SNN): The catchment area within a 60-minute commute has a 580.000 population. With recently completed road improvements, this population has increased to one million within a 90-minute commute. It is located on the west coast of the country and has an important place in aviation history. With 453.594 tons of air cargo annually, it has a significant impact on the trade of the country (TheRouteShop, 2022-c).

Shannon Airport hosted 380.000 passengers in 2021, an increase of 8% compared to 2020. However, the destination is still far from its good old days, with 1.717.000 passengers in 2019 (HospitalityIreland, 2022).

Alternative 5 (WLG): Wellington is the second largest city in New Zealand, and its economy generates the country's highest GDP per capita due to the high proportion of business and financial services. WLG airport is located in the center of the country and is seven kilometers from the city center. The population of Wellington's city area is 430.000. Furthermore, about 490.000 people are within an immediate catchment area while 720.000 people live within 2 hours drive circle from the Airport.

WLG is a high-yielding aviation market underserved by international flights and unserved long-haul routes. 18% of aviation transport is for business purposes. Its long-haul markets include 161.000 to/from Asia, 151.000 to/from Europe, 125.000 to/from the Americas, 26.000 to/from the Middle East/Africa with no direct flights to Asia/the Americas, and no one-stop options to Europe. With limited cargo capacity due to the wide-bodied aircraft, WLG's share of the air cargo business was only 0,4 % (1.500 tons or US\$53 million) despite the presence of long-haul services (TheRouteShop, 2022-d).

3.5.2. Application of Interval-Valued Pythagorean Fuzzy AHP

In the second stage, the weights of selected criteria are calculated by applying the Interval-valued Pythagorean Fuzzy AHP method. Nine network development experts are asked to evaluate these criteria by pair-wise comparison with the given linguistic scale.

Step 1: Firstly, the main criteria listed in Table 3.3 are subjected to pair-wise comparison, then the sub-criteria are subjected to pair-wise comparison by nine expert decision-makers. The decision-makers used the linguistic terms in Table 3.1 to express their pair-wise comparison of criteria. The pair-wise comparison was conducted via a questionnaire as shown in Appendix A from Table A.1. to Table A.10.

The linguistic terms of the pair-wise comparison matrices, which express the evaluation of decision-makers, are transferred into interval-valued PFNs. The pair-wise comparisons of criteria, that are transferred into interval-valued PFNs, are presented in Appendix B Table B.1.

Then, to represent group decisions and preferences, the nine decision-makers individual criteria evaluations are aggregated, and group decision matrices of criteria are shown in Appendix B Table B.2.

Step 2: The difference matrices (D) are calculated with Equation 3.7 and Equation 3.8. The difference matrix of the main criteria is presented in Table 3.4., and the difference matrix of sub-criteria social/economic conditions is presented in Table 3.5.

Table 3.4. Difference Matrix of Main Criteria

	d _L	d _U	d _L	d _U	d _L	d _U	d _L	d _U
Social/Economic Conditions	0,000	0,000	-0,159	0,054	-0,515	-0,284	0,077	0,175
Cost	-0,054	0,159	0,000	0,000	0,361	0,509	0,327	0,491
Demand	0,284	0,515	-0,509	-0,361	0,000	0,000	0,274	0,398
Competitiveness	-0,175	-0,077	-0,491	-0,327	-0,398	-0,274	0,000	0,000

Table 3.5. Difference Matrix of Sub-criteria (Social/Economic Conditions)

	d _L	d _U	d _L	d _U	d _L	d _U
City Population /Catchment Area	0,000	0,000	-0,373	-0,134	-0,510	-0,348
Income (GDP) and Trade	0,134	0,373	0,000	0,000	-0,070	0,196
Tourism Potential	0,348	0,510	-0,196	0,070	0,000	0,000

Step 3: The interval multiple matrices, S , are calculated with Equation 3.9 and Equation 3.10. The interval multiple (S) matrix of the main criteria is shown in Table 3.6., and the interval multiple (S) matrix of sub-criteria social/economic conditions is shown in Table 3.7.

Table 3.6. Interval Multiple (S) Matrix of Main Criteria

	S_L	S_U	S_L	S_U	S_L	S_U	S_L	S_U
Social/Economic Conditions	1,000	1,000	0,577	1,206	0,169	0,374	1,304	1,832
Cost	0,829	1,732	1,000	1,000	3,484	5,799	3,097	5,442
Demand	2,670	5,923	0,172	0,287	1,000	1,000	2,576	3,959
Competitiveness	0,546	0,767	0,184	0,323	0,253	0,388	1,000	1,000

Table 3.7. Interval Multiple (S) Matrix of Sub-criteria (Social/Economic Conditions)

	S_L	S_U	S_L	S_U	S_L	S_U
City Population /Catchment Area	1,000	1,000	0,275	0,629	0,172	0,301
Income (GDP) and Trade	1,589	3,632	1,000	1,000	0,784	1,965
Tourism Potential	3,327	5,831	0,509	1,275	1,000	1,000

Step 4: The determinacy values are calculated with Equation 3.11. The determinacy value of the main criteria is presented in Table 3.8., and the determinacy value of sub-criteria social/economic conditions is presented in Table 3.9.

Table 3.8. The Determinacy Value of Main Criteria

	h	h	h	h
Social/Economic Conditions	1,000	0,787	0,769	0,902
Cost	0,787	1,000	0,852	0,837
Demand	0,769	0,852	1,000	0,876
Competitiveness	0,902	0,837	0,876	1,000

Table 3.9. The Determinacy Value of Sub-criteria (Social/Economic Conditions)

	h	h	h
City Population / Catchment Area	1,000	0,761	0,838
Income (GDP) and Trade	0,761	1,000	0,734
Tourism Potential	0,838	0,734	1,000

Step 5: Before weighting the criteria, the normalization (t) matrices are calculated with Equation 3.12. The normalization matrix of the main criteria is presented in Table 3.10., and the normalization matrix of social/economic conditions is presented in Table 3.11.

Table 3.10. The Normalization (t) Matrix of Main Criteria

	t	t	t	t
Social/Economic Conditions	1,000	0,701	0,209	1,414
Cost	1,007	1,000	3,956	3,573
Demand	3,306	0,196	1,000	2,861
Competitiveness	0,592	0,212	0,280	1,000

Table 3.11. The Normalization (t) Matrix of Sub-criteria (Social/Economic Conditions)

	t	t	t
City Population / Catchment Area	1,000	0,344	0,198
Income (GDP) and Trade	1,986	1,000	1,009
Tourism Potential	3,835	0,655	1,000

Step 6: Normalized priority weight of each criterion is calculated with Equation 3.13. Weights of the main criteria, local weights, and global weights of sub-criteria are shown below in Table 3.12.

Table 3.12. Weights of Criteria

Main Criteria	Weight	Sub-Criteria	Local Weight	Global Weight
Social/Economic Conditions	15%	City Population / Catchment Area	14%	2%
		Income (GDP) and Trade	36%	5%
		Tourism Potential	50%	7%
Cost	43%	Distance (Distance*Fuel)	73%	31%
		Route Cost	27%	12%
Demand	33%	Number of Economy Passengers	13%	4%
		Number of Business Passengers	10%	3%
		Number of Connecting Passengers	63%	21%
		Cargo Capacity	14%	5%
Competitiveness	9%	Price (Fare)	13%	1%
		Number of Competitor Airlines	25%	2%
		Frequency of Competitors	62%	6%

3.5.3. Application of Interval-Valued Pythagorean Fuzzy WASPAS Method

In this section, five alternative routes are ranked with the Interval-valued Pythagorean Fuzzy WAPAS method. Firstly, evaluation matrices are created with the performance value of each alternative with respect to each criterion by the evaluation of five decision-makers using the linguistic variables in Table 3.2. The linguistic evaluation of five alternative routes is shown in Table 3.13.

Table 3.13. Linguistic Evaluation of Five Alternative Routes

DM	Alternatives	C ₁₁	C ₁₂	C ₁₃	C ₂₁	C ₂₂	C ₃₁	C ₃₂	C ₃₃	C ₃₄	C ₄₁	C ₄₂	C ₄₃
EDM ₁	A1	NG	VG	FG	B	NG	VG	VG	G	NG	VG	VG	FG
	A2	G	FG	FG	B	NG	VG	VG	FG	FG	VG	VG	FG
	A3	NG	FG	FG	B	NG	VG	VG	VG	NG	VG	VG	FG
	A4	B	G	NG	G	G	NG	B	FB	NG	VG	VG	VG
	A5	B	VG	NG	VB	G	G	FG	G	VB	VG	VG	FG
EDM ₂	A1	FG	VG	VG	NG	FG	G	NG	B	NG	G	NG	NG
	A2	VG	FG	VG	NG	FG	VG	VG	NG	VG	G	G	NG
	A3	G	FG	VG	NG	G	VG	G	VG	B	G	G	B
	A4	B	NG	B	VG	VG	VB	VB	VB	NG	NG	VG	VG
	A5	B	FG	B	B	VG	FB	B	FB	VB	VG	G	B
EDM ₃	A1	NG	VG	VG	NG	NG	FG	G	G	G	G	B	NG
	A2	VG	FG	VG	NG	NG	VG	VG	FG	VG	FG	G	NG
	A3	NG	FG	FG	NG	B	VG	FG	VG	B	FG	NG	FB
	A4	B	B	VB	VG	G	VB	VB	VB	G	B	VG	FG
	A5	B	VG	FB	VB	FG	FB	NG	NG	FB	B	G	B
EDM ₄	A1	FG	VG	VG	B	NG	FG	FG	G	G	NG	B	FG
	A2	VG	FG	FG	B	NG	VG	VG	G	FG	NG	NG	G
	A3	FG	FG	FG	B	B	VG	FG	VG	B	G	NG	G
	A4	G	G	NG	VG	FG	B	NG	B	G	VG	VG	VG
	A5	NG	NG	G	FB	FG	B	G	NG	VG	VG	NG	G
EDM ₅	A1	G	G	VG	FG	G	G	NG	NG	G	G	NG	G
	A2	FG	FB	FG	FG	VG	NG	G	G	G	FG	FG	FG
	A3	NG	NG	FG	NG	G	VG	FG	VG	FG	VG	B	FB
	A4	B	FG	NG	VG	VG	B	VB	B	FG	B	FG	G
	A5	B	VG	G	B	FG	FG	VG	FG	B	NG	NG	B

Then, the evaluation matrix of each expert is transferred into the corresponding Interval-valued Pythagorean fuzzy numbers. The combined evaluation matrix of the five decision-makers is shown in Appendix C, Table C.1.

After having the aggregated decision matrix of all five experts, the steps of the Interval-valued Pythagorean Fuzzy WASPAS method are applied as follows;

Step 1: The decision matrix normalized with Equation 3.14. The normalized matrix and the maximum values are presented in Table 3.14.

Step 2: The normalization matrix is transferred into the Pythagorean normalized matrix and is presented in Appendix C, Table C.2.

Table 3.14. Normalization Matrix and Maximum Values

	μ_L	μ_L	μ_L	μ_L	μ_L	max	1/max
C ₁₁	0,664	0,795	0,627	0,448	0,430	0,795	1,25864
C ₁₂	0,814	0,664	0,719	0,609	0,776	0,814	1,22921
C ₁₃	0,833	0,795	0,776	0,466	0,519	0,833	1,20099
C ₂₁	0,537	0,537	0,501	0,814	0,305	0,814	1,22921
C ₂₂	0,627	0,664	0,537	0,757	0,757	0,757	1,32146
C ₃₁	0,738	0,795	0,852	0,359	0,483	0,852	1,17391
C ₃₂	0,682	0,814	0,757	0,323	0,646	0,814	1,22921
C ₃₃	0,591	0,682	0,852	0,305	0,573	0,852	1,17391
C ₃₄	0,627	0,776	0,501	0,646	0,395	0,776	1,28936
C ₄₁	0,682	0,719	0,757	0,609	0,701	0,757	1,32146
C ₄₂	0,555	0,701	0,609	0,833	0,664	0,833	1,20099
C ₄₃	0,664	0,664	0,483	0,795	0,519	0,795	1,25864

Step 3: The calculated criteria weights with Interval-valued Pythagorean Fuzzy AHP are assigned to the normalized decision matrix, then **WSM** (Q_i^1) and **WPM** (Q_i^2) values are calculated using Equations 3.15 and 3.16.

The calculation of WSM and the WSM (Q_i^1) values for each alternative are shown in Appendix C, Table C.3., and Table C.4. The calculation of WPM and the WPM (Q_i^2) values for each alternative are shown in Appendix C, Table C.5., and Table C.6.

Step 4: The calculated WSM and WPM values are aggregated using Equation 3.17 with $\lambda=0,5$. Q_i values and rankings of alternatives are given in Table 3.15.

Table 3.15. Ranking of Alternatives

Alternatives	Q_i	Rank
A1	0,678	3
A2	0,709	1
A3	0,700	2
A4	0,671	4
A5	0,557	5

Finally, Q_i values of each alternative are calculated with changing λ values. We swing λ between 0 and 1. The results of the sensitivity analysis are shown in Table 3.16, with the rankings presented in parenthesis under the Q_i values. When the λ is closer to 0, the WPM model is given priority to determine the rankings, whereas the λ is closer to 1 means that the WSM model is prioritized.

Table 3.16. Ranking of Alternative with Changing of λ Values

λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
A1	0,662 (2)	0,666 (3)	0,669 (3)	0,672 (3)	0,675 (3)	0,678 (3)	0,681 (4)	0,684 (4)	0,687 (4)	0,690 (4)	0,693 (3)
A2	0,694 (1)	0,698 (1)	0,701 (1)	0,703 (1)	0,706 (1)	0,709 (1)	0,712 (1)	0,715 (2)	0,718 (2)	0,720 (3)	0,723 (2)
A3	0,662 (2)	0,671 (2)	0,679 (2)	0,687 (2)	0,695 (2)	0,702 (2)	0,709 (2)	0,716 (1)	0,723 (1)	0,730 (1)	0,736 (1)
A4	0,584 (3)	0,604 (4)	0,622 (4)	0,640 (4)	0,656 (4)	0,671 (4)	0,686 (3)	0,699 (3)	0,712 (3)	0,724 (2)	0,736 (1)
A5	0,504 (4)	0,516 (5)	0,527 (5)	0,537 (5)	0,547 (5)	0,557 (5)	0,567 (5)	0,576 (5)	0,585 (5)	0,594 (5)	0,602 (4)

CHAPTER IV

RESULTS & DISCUSSION

In this section, first, the findings of the Interval-valued Pythagorean Fuzzy AHP, and then the findings obtained with the Interval-valued Pythagorean Fuzzy WASPAS method will be discussed.

4.1. Findings of Interval-Valued Pythagorean Fuzzy AHP

The steps of Interval-valued Pythagorean Fuzzy AHP are applied to find out the weights of each route selection criteria in Section 3.2.2, and the weight of each criterion is calculated. The comparison of the main criteria with weights is shown in Figure 4.1.

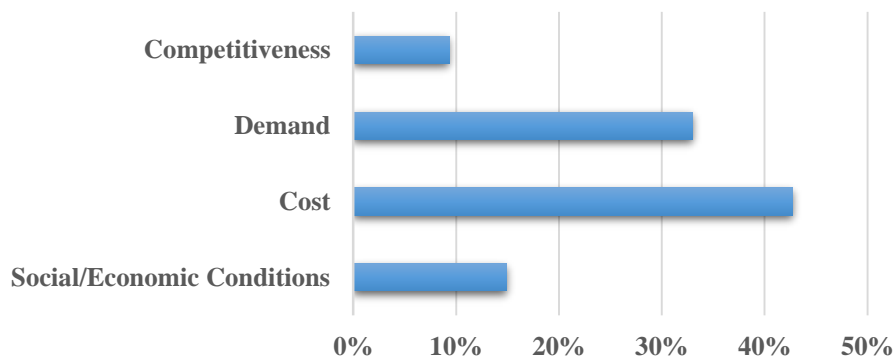


Figure 4.1. Weights of Main Criteria

The results show that the cost (43% weight) and demand (33% weight) substantially impact route selection decisions whereas social/economic conditions (15% weight) and competitiveness (9% weight) are attached less importance by the experts.

The effect of route cost has great importance when evaluating a route. There should be a potential demand when selecting a new route so that this would be profitable. Namely, the revenue of passenger demand should cover the cost of the route. Considering the studies based on the cost criteria for route selection, we may confirm

the outcome of this study. The airline company to which we carried out this study also draws attention to the cost criterion while making the route selection decisions. Besides this, many other studies on this subject consider the cost criterion as an important criterion. Gaggero and Piazza (2021) mentioned that cost has a negative effect on the route selection decision and indicated that the longer route, the lower probability of entry. Birolini et al. (2021) formulated the airline network planning, including route selection based on demand and cost with profit-maximization. Thekinen et al. (2020) emphasized the negative effect of increasing the cost of adding a new route. In line with our findings, Deveci et al. (2017) compared eleven criteria, including route distance, with the highest weight.

In the following pages, we will evaluate the importance attached to each sub-criterion by the experts.

Social/economic conditions (C_1): Considering the social/economic conditions main criterion, tourism potential has the biggest share with a local weight of 50 %. Income/trade is the second with 36%, while the population/catchment area is the last one with 14%, as presented in Figure 4.2. When evaluated over the twelve criteria, tourism potential with the global weight of 7% is the fourth criterion, income/trade with the global weight of 5% is the sixth, and population/catchment area with a global weight of 2% is the second lowest criterion.



Figure 4.2. Weights of Sub-criteria (Social/economic conditions)

Looking into these criteria, we could view that the tourism potential of any route impacts the passenger demand for arrival flights, whereas population and income (GDP) impact the passenger demand for departure flights. The passenger demand that depends on the city population, would be limited by the number of people who lives there. Also, the passenger demand, depending on the GDP, would be the same. On the other hand, the tourism potential of a destination would increase the passenger demand for the route. The developing tourism of a city would attract more people to fly there. Both the airline and the destination city would save when more passenger arrives. We can understand this when we compare the importance weights of each criterion.

Cost C₂: Analyzing the most important main criterion, “cost”, sub-criterion distance (fuel consumption), is the first criterion both in local weight and global weight with 73 % and 31%. Route cost other than fuel consumption has 27% local weight, and it is the third criterion with 12 % global weight, as presented in Figure 4.3.

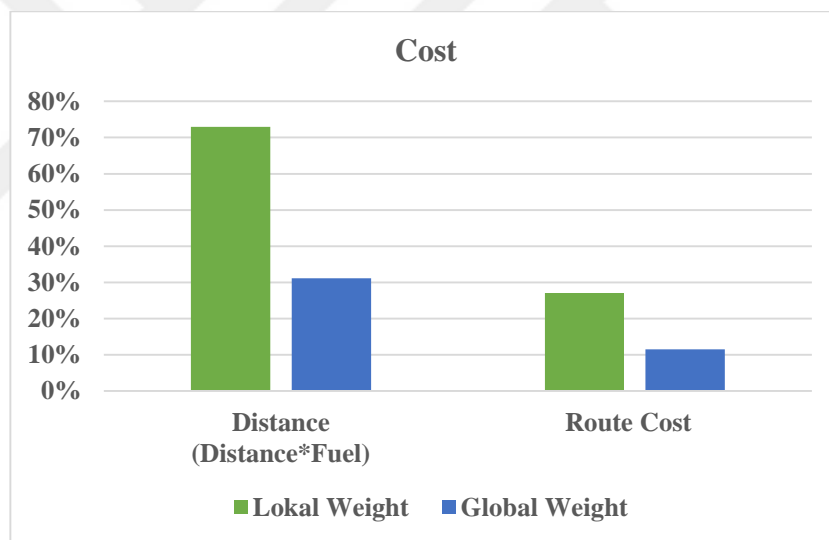


Figure 4.3. Weights of Sub-criteria (Cost)

Because of having little control over the cost items such as fuel, airport charges, aircraft ownership, etc., the cost criterion can be seen as the most important criterion for selecting a new route. Considering the cost structure of airlines, fuel consumption has the most significant share. As usual, fuel is the airline industry’s most significant cost item in 2022 at 19,5% (see Figure 4.5). Although airlines use hedging methods to overcome fuel consumption-related problems, this cost item affects the profitability of

airlines. Also, route costs other than fuel consumption have a significant proportion of total operational costs like airport expenses and operating crew expenses.

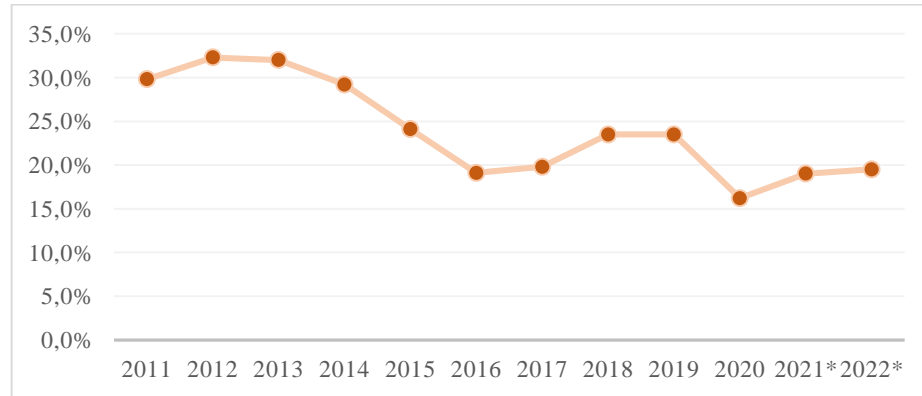


Figure 4.4. Percentage Share of Expenditure of Fuel Cost in Total Cost from 2011 to 2022

Source: Statista, 2022

Demand C₃: When we examine the second most important main criterion, “demand,” the number of connecting passengers is the first criterion within the group with 63% local weight. Additionally, it is the second criterion over the twelve criteria with a 21% global weight. Cargo capacity is the second in its group with 14% local weight and is the sixth criterion overall with 5% global weight. The number of economy passengers and the number of business passengers are the seventh and eighth criteria, respectively, with 13% and 10% global weight, as presented in Figure 4.6.

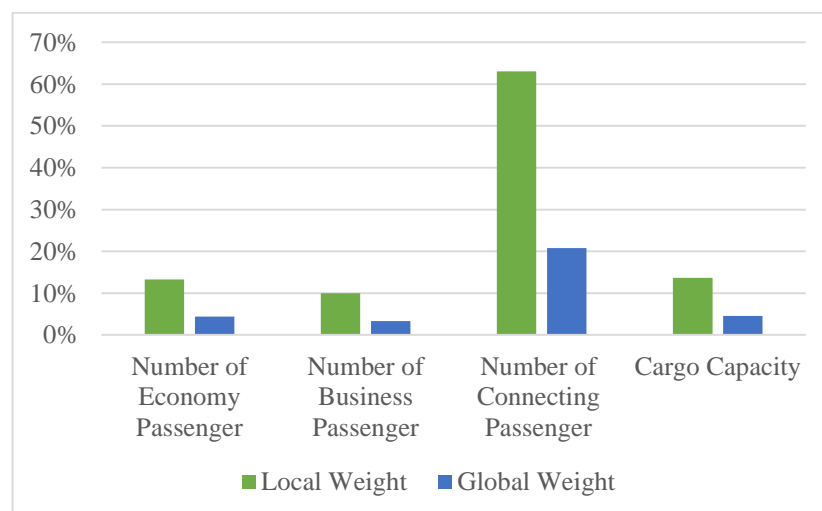


Figure 4.5. Weights of Sub-criteria (Demand)

Although the connecting passenger number has the most significant share on the demand side, this situation varies regarding the network type of an airline, whether it is a network carrier of a hub and spoke airline or it has the network structure of only flying from point to point.

In the hub and spoke network, the airlines not only transport passengers between two points but also connect the passengers via their hub. Such airlines are interested in passenger demand of connecting passengers. In this model, the airlines have a high potential for transit traffic in their hub because of transferring passengers.

On the other hand, a point-to-point network has only the passenger demand between origin and destination (OD) city pairs. In other words, this kind of airline is only interested in transporting the passengers from origin to destination and is not interested in connecting passengers between this OD city pair via another point.

We could say that the number of connecting passengers has meaningful importance for network airlines, unlike low-cost airlines.

When we look at the cargo capacity sub-criterion, it has an impact if an airline transports air cargo in the holds of passenger aircraft with passenger flights. We could say that nearly every passenger flight carries some cargo in the holds with the passenger baggage. With such a business model, the revenue of that flight would be higher and impacts the profitability of the route beside the passenger revenue.

Competitiveness C4: As we mentioned before, competitiveness is the least preferred main criterion with a weight of 9%. In this main criterion, frequency of competitors is the first criterion with 62% local weight and the fifth criterion overall with 6% global weight, the number of competitor airlines is the second in its group with 25% local weight and the ninth criterion overall with 2% global weight. The price of the route is the least at both local and global, respectively, with the weight of 13% and 1%, as presented below in Figure 4.7.

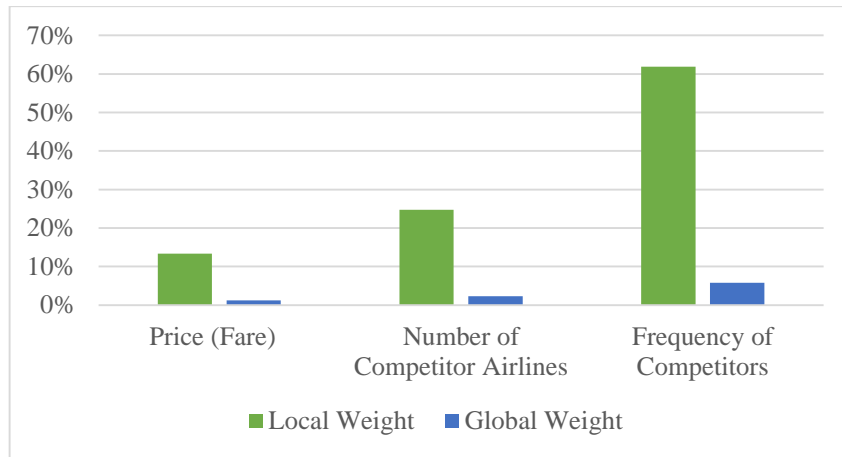


Figure 4.6. Weights of Sub-criteria (Competitiveness)

The airline industry is a competitive market in that airlines have to make decisions on fares and frequencies of service in this competitive environment. The price of the route would be created with the demand and supply curve, and usually, the existing competitors would determine the fare. If an airline wants to get a market share in that route, the number of competitors' flights and the time of competitors' existing flights would be important when deciding. The more frequent flight of competitors means more alternatives for a passenger. So, this criterion has the biggest share in its group. On the other hand, the effect of the number of competitors would decrease with the alliances between airlines.

4.2. Findings of Interval-Valued Pythagorean Fuzzy WASPAS Method

The steps of Interval-valued Pythagorean Fuzzy WASPAS are applied for the ranking of the five routes in section 3.2.3. The rankings are presented in Table 4.1.

Of the five alternative routes, the first three are in the North America region, DFW, DEN, and SEA, the other routes SNN and WLG, are in Northern Europe and southeastern Australia. Comparing the alternative routes based on the findings, we could examine that both the cost and the demand criteria have an impact on this selection. Although the first three destinations are in the same region with nearly the same distance, the demand factor mainly affects this selection.

Table 4.1. Ranking of Five Alternative Routes

Alternatives Routes	Rank
SEA	3
DFW	1
DEN	2
SNN	4
WLG	5

As mentioned before, the WASPAS method combines two ranking models, WSM and WPM. The effect of these models on the WASPAS method is balanced with the λ value, which is between 0 and 1. Alternating λ could change the ranking of alternatives. While we used 0,5, the effects of other λ values are graphed in Figure 4.8.

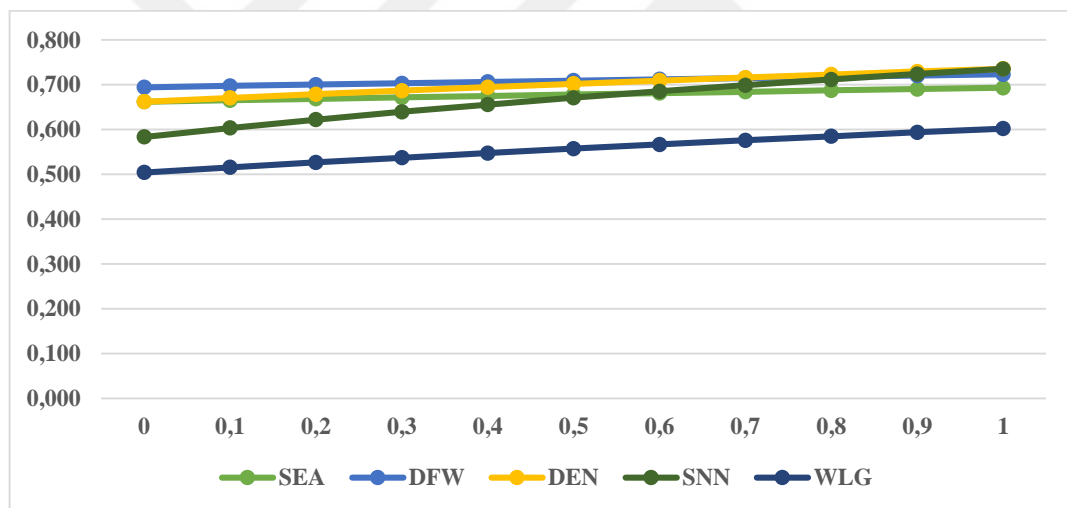


Figure 4.7. The Effect of Changing λ Values on Route Ranking

The ranking of alternatives does not change until the λ value of 0,6. Also, the ranking of alternative five WLG does not change with changing λ values. After the λ value of 0,6, the ranking of the first three routes, which are in the same region with almost the same distance, are exchanged with each other. Alternatively, SNN also included the ranking after λ gets the value of 0,6 because of the distance of the route, which is closer to the first three routes. The changing of ranking with increasing λ values is caused by the effect of the distance, in other words, with the effect of cost.

CHAPTER V

CONCLUSIONS

This research is about designing a hybrid MCDM model to find a feasible solution to the new route selection problem of an airline, a problem considered one of the essential decisions in aviation management. The first part of the model presented in this study, Interval-valued Pythagorean Fuzzy AHP, allows to network developer to evaluate criteria in linguistic terms. The second part of the model presented in this study, Interval-valued Pythagorean Fuzzy WASPAS, ranks the alternative routes and selects the most appropriate alternative.

To conclude, all of the objectives of this research which were formulated in Chapter One, have been achieved. More precisely, first, a new hybrid Interval-valued Pythagorean Fuzzy AHP and Interval-valued Pythagorean Fuzzy WASPAS model for airline route selection problem is designed and applied to a real-world case of a prominent airline company.

Second, the model transfers decision-makers' experience from the linguistic world to the numerical one with Pythagorean Fuzzy Numbers. Third, the importance of factors, that affect the route selection, are determined after a detailed examination, and they are evaluated with the help of Interval-valued Pythagorean Fuzzy AHP. Then, the weights of the selected factors are determined.

Lastly, the alternative airline routes are ranked, and the most suitable route is indicated.

The study results show that many factors affect the airline route selection problem, and each factor does not have equal importance when selecting a new one. There would be detailed work on determining the evaluating criteria between these factors.

5.1. Contributions

In a conclusion, this research proposes a novel model for the airline route selection problem. There are limited studies on route selection problems using MCDM methods. Considering the studies using MCDM methods for solving the researched subject, the applied hybrid model is the main novelty of this study.

In terms of managerial implications, a new method for airline management to deal with network development decisions is elaborated in this research. The proposed model would guide the airline management to invest in the right routes.

5.2. Limitations and Future Work

This research was based on an interview with the network development department of a full-service network airline. The limitation is that the decision-makers would have similar perspectives. Application of the model to different airlines would confirm the validity of the model, which must be tested in different settings, such as varying airline business models, regions, companies, and fleet compositions.

Hybridizing other recent MCDM methods may be one of the future research directions. Obviously, the output of the proposed model can be used as input for some decisions on the operational level, such as flight frequency and slot allocation decisions.

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APPENDIXES

APPENDIX A

Table A.1. Airline Route Selection Pairwise Comparison Questionnaire

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁					Social conditions of the route.
C ₂					The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃					Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁					The catchment areas will give information about the estimated demand.
C ₁₂					Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁					The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁					Passengers fly for leisure purposes.
C ₃₂					Passengers fly for business purposes and very often.
C ₃₃					Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁					The average fare of other airlines operates on this route.
C ₄₂					The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		LI	VLI	LI	Social conditions of the route.
C ₂			AAI	AI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				BAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		VHI	AAI		The catchment areas will give information about the estimated demand.
C ₁₂			LI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		AI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AAI	LI	BAI	Passengers fly for leisure purposes.
C ₃₂			LI	BAI	Passengers fly for business purposes and very often.
C ₃₃				VHI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		AI	AI		The average fare of other airlines operates on this route.
C ₄₂			AI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		LI	VLI	LI	Social conditions of the route.
C ₂			AAI	AI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				BAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		VHI	AAI		The catchment areas will give information about the estimated demand.
C ₁₂			LI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		AI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AAI	LI	BAI	Passengers fly for leisure purposes.
C ₃₂			LI	BAI	Passengers fly for business purposes and very often.
C ₃₃				VHI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		AI	AI		The average fare of other airlines operates on this route.
C ₄₂			AI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	BAI	AAI	Social conditions of the route.
C ₂			AI	BAI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				HI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		BAI	LI		The catchment areas will give information about the estimated demand.
C ₁₂			BAI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		AAI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AI	CLI	VLI	Passengers fly for leisure purposes.
C ₃₂			CLI	VLI	Passengers fly for business purposes and very often.
C ₃₃				CHI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		HI	AAI		The average fare of other airlines operates on this route.
C ₄₂			BAI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		BAI	VLI	LI	Social conditions of the route.
C ₂			AI	AAI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				BAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		LI	LI		The catchment areas will give information about the estimated demand.
C ₁₂			LI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		CHI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		VHI	LI	AI	Passengers fly for leisure purposes.
C ₃₂			LI	LI	Passengers fly for business purposes and very often.
C ₃₃				AAI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		LI	VLI		The average fare of other airlines operates on this route.
C ₄₂			LI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	LI	BAI	Social conditions of the route.
C ₂			HI	CHI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				AAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		VLI	LI		The catchment areas will give information about the estimated demand.
C ₁₂			HI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		AAI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AI	LI	AAI	Passengers fly for leisure purposes.
C ₃₂			LI	AAI	Passengers fly for business purposes and very often.
C ₃₃				AI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		LI	VLI		The average fare of other airlines operates on this route.
C ₄₂			LI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

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

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	VLI	LI	Social conditions of the route.
C ₂			VHI	VHI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				AAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		LI	BAI		The catchment areas will give information about the estimated demand.
C ₁₂			VHI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		HI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AI	LI	AAI	Passengers fly for leisure purposes.
C ₃₂			LI	AAI	Passengers fly for business purposes and very often.
C ₃₃				AI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		LI	VLI		The average fare of other airlines operates on this route.
C ₄₂			LI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

Table A.8. Airline Route Selection Pairwise Comparison Questionnaire (DM7)

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	BAI	LI	Social conditions of the route.
C ₂			CHI	HI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				AAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		LI	VLI		The catchment areas will give information about the estimated demand.
C ₁₂			HI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		HI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AAI	VLI	AI	Passengers fly for leisure purposes.
C ₃₂			LI	AAI	Passengers fly for business purposes and very often.
C ₃₃				AAI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		VLI	LI		The average fare of other airlines operates on this route.
C ₄₂			VLI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

Table A.9. Airline Route Selection Pairwise Comparison Questionnaire (DMs)

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	AAI	CHI	Social conditions of the route.
C ₂			AAI	CHI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				CHI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		BAI	AAI		The catchment areas will give information about the estimated demand.
C ₁₂			HI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		HI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		BAI	AI	AI	Passengers fly for leisure purposes.
C ₃₂			AAI	AAI	Passengers fly for business purposes and very often.
C ₃₃				LI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		BAI	LI		The average fare of other airlines operates on this route.
C ₄₂			AI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

Table A.10. Airline Route Selection Pairwise Comparison Questionnaire (DM9)

<p>We thank you in advance for your contribution with your expertise in this study that we have carried out to select a new airline route. At this stage of the study, we asked for opinions to determine the importance degrees of the criteria used in the selection of the new route. In the five pair-wise comparison tables given below, fill only the green marked fields according to your subjective evaluation in accordance with the coding in the given scale.</p> <p>For example, in terms of route selection when assessing the relative importance of "Social/Political Criteria" relative to "Cost Criteria", If you say selection criteria "Social/political" is "very low important" comparing selection criteria "cost" you should put "VLI" to the E20 cell. This means Social/political importance is between 10%-20%, and cost importance is between 90%-100% when we compare these two criteria. Thank you for your support with your expertise.</p>					
Route Selection	C ₁	C ₂	C ₃	C ₄	Description
C ₁		AI	LI	BAI	Social conditions of the route.
C ₂			HI	CHI	The total cost of the route includes fuel, crew, airport charges, handling, and other expenses.
C ₃				AAI	Total passenger demand of the route.
C ₄					Comparison with the other airlines based on the route.
Social/Economic Conditions	C ₁₁	C ₁₂	C ₁₃		Description
C ₁₁		BAI	LI		The catchment areas will give information about the estimated demand.
C ₁₂			HI		Income and GDP indicate the purchasing power of the destination city, which is the endpoint of the route.
C ₁₃					The high tourism potential of the destination points is an advantage for airlines.
Cost	C ₂₁	C ₂₂			Description
C ₂₁		HI			The flight distance of the route and the quantity of fuel used for the route.
C ₂₂					The cost is other than distance *fuel.
Demand	C ₃₁	C ₃₂	C ₃₃	C ₃₄	Description
C ₃₁		AI	LI	AAI	Passengers fly for leisure purposes.
C ₃₂			LI	AAI	Passengers fly for business purposes and very often.
C ₃₃				AI	Indicates the number of passengers going to and coming from another city via a connecting flight.
C ₃₄					Cargo demand from this route
Competitiveness	C ₄₁	C ₄₂	C ₄₃		Description
C ₄₁		AAI	BAI		The average fare of other airlines operates on this route.
C ₄₂			LI		The number of airlines that operate on this route.
C ₄₃					The number of flights operated by other airlines.

APPENDIX B

Table B.1. The Pairwise Comparison Matrix Of Main Criteria With PFNs

	MAIN CRITERIA	Social /Economic Conditions				Cost				Demand				Competitiveness			
		μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U
DM ₁	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,55	0,65	0,35	0,45	0,2	0,35	0,65	0,8	0,1	0,2	0,8	0,9
	Cost	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965	0,55	0,65	0,35	0,45	0,2	0,35	0,65	0,8
	Demand	0,65	0,8	0,2	0,35	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55
	Competitiveness	0,8	0,9	0,1	0,2	0,65	0,8	0,2	0,35	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965
DM ₂	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8	0,1	0,2	0,8	0,9	0,2	0,35	0,65	0,8
	Cost	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965	0,55	0,65	0,35	0,45	0,45	0,55	0,45	0,55
	Demand	0,8	0,9	0,1	0,2	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65
	Competitiveness	0,65	0,8	0,2	0,35	0,45	0,55	0,45	0,55	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965
DM ₃	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,35	0,45	0,55	0,65	0,55	0,65	0,35	0,45
	Cost	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,35	0,45	0,55	0,65
	Demand	0,55	0,65	0,35	0,45	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965	0,65	0,8	0,2	0,35
	Competitiveness	0,35	0,45	0,55	0,65	0,55	0,65	0,35	0,45	0,2	0,35	0,65	0,8	0,1965	0,1965	0,1965	0,1965
DM ₄	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65	0,1	0,2	0,8	0,9	0,2	0,35	0,65	0,8
	Cost	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,55	0,65	0,35	0,45
	Demand	0,8	0,9	0,1	0,2	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65
	Competitiveness	0,65	0,8	0,2	0,35	0,35	0,45	0,55	0,65	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965

Table B.1. (Cont.)

	MAIN CRITERIA	Social /Economic Conditions				Cost				Demand				Competitiveness			
		μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
DM ₅	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,2	0,35	0,65	0,8	0,35	0,45	0,55	0,65
	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	0,9	1	0	0
	Demand	0,65	0,8	0,2	0,35	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	0,55	0,65	0,35	0,45	0	0	0,9	1	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965
DM ₆	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,1	0,2	0,8	0,9	0,2	0,35	0,65	0,8
	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	0,8	0,9	0,1	0,2
	Demand	0,8	0,9	0,1	0,2	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	0,65	0,8	0,2	0,35	0,1	0,2	0,8	0,9	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965
DM ₇	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,35	0,45	0,55	0,65	0,2	0,35	0,65	0,8
	Cost	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965	0,9	1	0	0	0,65	0,8	0,2	0,35
	Demand	0,55	0,65	0,35	0,45	0	0	0,9	1	0,1965	0,1965	0,1965	0,1965	0,55	0,65	0,35	0,45
	Competitiveness	0,65	0,8	0,2	0,35	0,2	0,35	0,65	0,8	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965
DM ₈	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	0,9	1	0	0
	Cost	0,45	0,55	0,45	0,55	0,1965	0,1965	0,1965	0,1965	0,55	0,65	0,35	0,45	0,9	1	0	0
	Demand	0,35	0,45	0,55	0,65	0,35	0,45	0,55	0,65	0,1965	0,1965	0,1965	0,1965	0,9	1	0	0
	Competitiveness	0	0	0,9	1	0	0	0,9	1	0	0	0,9	1	0,1965	0,1965	0,1965	0,1965
DM ₉	Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,45	0,55	0,45	0,55	0,2	0,35	0,65	0,8	0,35	0,45	0,55	0,65
	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	0,9	1	0	0
	Demand	0,65	0,8	0,2	0,35	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	0,55	0,65	0,35	0,45	0	0	0,9	1	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 Criteria With PFNs

	Social/Economic Conditions	City Population/Catchment Area				Income (GDP) and Trade				Tourism Potential			
		μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	N
DM ₁	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,1	0,2	0,8	0,9	0	0	0,9	1
	Income (GDP) and Trade	0,8	0,9	0,1	0,2	0,1965	0,1965	0,1965	0,1965	0,1	0,2	0,8	0,9
	Tourism Potential	0,9	1	0	0	0,8	0,9	0,1	0,2	0,1965	0,1965	0,1965	0,1965
DM ₂	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,8	0,9	0,1	0,2	0,55	0,65	0,35	0,45
	Income (GDP) and Trade	0,1	0,2	0,8	0,9	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8
	Tourism Potential	0,35	0,45	0,55	0,65	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965
DM ₃	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65	0,2	0,35	0,65	0,8
	Income (GDP) and Trade	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65
	Tourism Potential	0,65	0,8	0,2	0,35	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965
DM ₄	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8	0,2	0,35	0,65	0,8
	Income (GDP) and Trade	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8
	Tourism Potential	0,65	0,8	0,2	0,35	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965
DM ₅	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,1	0,2	0,8	0,9	0,2	0,35	0,65	0,8
	Income (GDP) and Trade	0,8	0,9	0,1	0,2	0,1965	0,1965	0,1965	0,1965	0,65	0,8	0,2	0,35
	Tourism Potential	0,65	0,8	0,2	0,35	0,2	0,35	0,65	0,8	0,1965	0,1965	0,1965	0,1965
DM ₆	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8	0,35	0,45	0,55	0,65
	Income (GDP) and Trade	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965	0,8	0,9	0,1	0,2
	Tourism Potential	0,55	0,65	0,35	0,45	0,1	0,2	0,8	0,9	0,1965	0,1965	0,1965	0,1965

Table B.2. (Cont.)

	Social/Economic Conditions	City Population/Catchment Area				Income (GDP) and Trade				Tourism Potential			
		μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	N
DM ₇	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,2	0,35	0,65	0,8	0,1	0,2	0,8	0,9
	Income (GDP) and Trade	0,65	0,8	0,2	0,35	0,1965	0,1965	0,1965	0,1965	0,65	0,8	0,2	0,35
	Tourism Potential	0,8	0,9	0,1	0,2	0,2	0,35	0,65	0,8	0,1965	0,1965	0,1965	0,1965
DM ₈	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65	0,55	0,65	0,35	0,45
	Income (GDP) and Trade	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965	0,65	0,8	0,2	0,35
	Tourism Potential	0,35	0,45	0,55	0,65	0,2	0,35	0,65	0,8	0,1965	0,1965	0,1965	0,1965
DM ₉	City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,35	0,45	0,55	0,65	0,2	0,35	0,65	0,8
	Income (GDP) and Trade	0,55	0,65	0,35	0,45	0,1965	0,1965	0,1965	0,1965	0,65	0,8	0,2	0,35
	Tourism Potential	0,65	0,8	0,2	0,35	0,2	0,35	0,65	0,8	0,1965	0,1965	0,1965	0,1965

Table B.3. Aggregating Pairwise Comparison Of Main Criteria

	Social /Economic Conditions				Cost				Demand				Competitiveness			
	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U
Social/Economic Conditions	0,1965	0,1965	0,1965	0,1965	0,4089	0,5211	0,4661	0,5712	0,2011	0,3290	0,6266	0,7453	0,2773	0,4186	0,0000	0,0000
Cost	0,4661	0,5712	0,4089	0,5211	0,1965	0,1965	0,1965	0,1965	0,6011	0,7134	0,0000	0,0000	0,5721	0,7004	0,0000	0,0000
Demand	0,6266	0,7453	0,2011	0,3290	0,0000	0,0000	0,6011	0,7134	0,1965	0,1965	0,1965	0,1965	0,5235	0,6312	0,0000	0,0000
Competitiveness	0,0000	0,0000	0,2773	0,4186	0,0000	0,0000	0,5721	0,7004	0,0000	0,0000	0,5235	0,6312	0,1965	0,1965	0,1965	0,1965

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

	City Population/Catchment Area				Income (GDP) and Trade				Tourism Potential			
	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U
City Population / Catchment Area	0,1965	0,1965	0,1965	0,1965	0,2410	0,3733	0,5229	0,6569	0,0000	0,0000	0,5900	0,7145
Income (GDP) and Trade	0,5229	0,6569	0,2410	0,3733	0,1965	0,1965	0,1965	0,1965	0,3881	0,5424	0,3141	0,4702
Tourism Potential	0,5900	0,7145	0,0000	0,0000	0,3141	0,4702	0,3881	0,5424	0,1965	0,1965	0,1965	0,1965

APPENDIX C

Table C.1. Group Decision Matrix Of Alternative Route Evaluation

X_{ij}	A1				A2				A3				A4				A5			
	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
C ₁₁	0,600	0,700	0,300	0,400	0,740	0,840	0,160	0,260	0,560	0,660	0,340	0,440	0,360	0,460	0,540	0,640	0,340	0,440	0,560	0,660
C ₁₂	0,760	0,860	0,140	0,240	0,600	0,700	0,300	0,400	0,660	0,760	0,240	0,340	0,540	0,640	0,360	0,460	0,720	0,820	0,180	0,280
C ₁₃	0,780	0,880	0,120	0,220	0,740	0,840	0,160	0,260	0,720	0,820	0,180	0,280	0,380	0,480	0,520	0,620	0,440	0,540	0,460	0,560
C ₂₁	0,460	0,560	0,440	0,540	0,460	0,560	0,440	0,540	0,420	0,520	0,480	0,580	0,760	0,860	0,140	0,240	0,200	0,300	0,700	0,800
C ₂₂	0,560	0,660	0,340	0,440	0,600	0,700	0,300	0,400	0,460	0,560	0,440	0,540	0,700	0,800	0,200	0,300	0,700	0,800	0,200	0,300
C ₃₁	0,680	0,780	0,220	0,320	0,740	0,840	0,160	0,260	0,800	0,900	0,100	0,200	0,260	0,360	0,640	0,740	0,400	0,500	0,500	0,600
C ₃₂	0,620	0,720	0,280	0,380	0,760	0,860	0,140	0,240	0,700	0,800	0,200	0,300	0,220	0,320	0,680	0,780	0,580	0,680	0,320	0,420
C ₃₃	0,520	0,620	0,380	0,480	0,620	0,720	0,280	0,380	0,800	0,900	0,100	0,200	0,200	0,300	0,700	0,800	0,500	0,600	0,400	0,500
C ₃₄	0,560	0,660	0,340	0,440	0,720	0,820	0,180	0,280	0,420	0,520	0,480	0,580	0,580	0,680	0,320	0,420	0,300	0,400	0,600	0,700
C ₄₁	0,620	0,720	0,280	0,380	0,660	0,760	0,240	0,340	0,700	0,800	0,200	0,300	0,540	0,640	0,360	0,460	0,640	0,740	0,260	0,360
C ₄₂	0,480	0,580	0,420	0,520	0,640	0,740	0,260	0,360	0,540	0,640	0,360	0,460	0,780	0,880	0,120	0,220	0,600	0,700	0,300	0,400
C ₄₃	0,600	0,700	0,300	0,400	0,600	0,700	0,300	0,400	0,400	0,500	0,500	0,600	0,740	0,840	0,160	0,260	0,440	0,540	0,460	0,560

Table C.2. Pythagorean Fuzzy Normalized Decision Matrix

r _{ij}	A1				A2				A3				A4				A5			
	μ _L	μ _U	ν _L	ν _U	μ _L	μ _U	ν _L	ν _U	μ _L	μ _U	ν _L	ν _U	μ _L	μ _U	ν _L	ν _U	μ _L	μ _U	ν _L	ν _U
C ₁₁	0,66	0,76	0,22	0,32	0,79	0,89	0,10	0,18	0,61	0,72	0,26	0,36	0,40	0,51	0,46	0,57	0,38	0,49	0,48	0,59
C ₁₂	0,81	0,90	0,09	0,17	0,65	0,75	0,23	0,32	0,71	0,81	0,17	0,27	0,59	0,69	0,28	0,38	0,77	0,86	0,12	0,21
C ₁₃	0,82	0,91	0,08	0,16	0,78	0,88	0,11	0,20	0,76	0,86	0,13	0,22	0,41	0,52	0,46	0,56	0,48	0,58	0,39	0,50
C ₂₁	0,50	0,61	0,36	0,47	0,50	0,61	0,36	0,47	0,46	0,57	0,41	0,51	0,81	0,90	0,09	0,17	0,22	0,33	0,65	0,76
C ₂₂	0,63	0,73	0,24	0,34	0,67	0,77	0,20	0,30	0,52	0,63	0,34	0,44	0,77	0,86	0,12	0,20	0,77	0,86	0,12	0,20
C ₃₁	0,72	0,82	0,17	0,26	0,78	0,87	0,12	0,21	0,84	0,93	0,07	0,15	0,28	0,39	0,59	0,70	0,43	0,54	0,44	0,55
C ₃₂	0,67	0,77	0,21	0,30	0,81	0,90	0,09	0,17	0,75	0,85	0,14	0,23	0,24	0,35	0,62	0,74	0,63	0,73	0,25	0,34
C ₃₃	0,56	0,66	0,32	0,42	0,66	0,76	0,22	0,32	0,84	0,93	0,07	0,15	0,22	0,32	0,66	0,77	0,54	0,64	0,34	0,44
C ₃₄	0,62	0,72	0,25	0,35	0,78	0,87	0,11	0,19	0,47	0,58	0,39	0,50	0,64	0,74	0,23	0,33	0,34	0,45	0,52	0,63
C ₄₁	0,69	0,79	0,19	0,28	0,73	0,82	0,15	0,24	0,77	0,86	0,12	0,20	0,60	0,71	0,26	0,36	0,71	0,81	0,17	0,26
C ₄₂	0,52	0,62	0,35	0,46	0,68	0,78	0,20	0,29	0,58	0,68	0,29	0,39	0,82	0,91	0,08	0,16	0,64	0,74	0,24	0,33
C ₄₃	0,66	0,76	0,22	0,32	0,66	0,76	0,22	0,32	0,44	0,55	0,42	0,53	0,79	0,89	0,10	0,18	0,49	0,59	0,38	0,48

Table C.3. The Calculation of WSM

WSM	A1				A2				A3				A4				A5			
	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U	μ_L	μ_U	ν_L	ν_U
C_{11}	0,11	0,13	0,97	0,98	0,14	0,18	0,95	0,97	0,10	0,12	0,97	0,98	0,06	0,08	0,98	0,99	0,06	0,08	0,98	0,99
C_{12}	0,24	0,29	0,88	0,91	0,17	0,21	0,92	0,94	0,19	0,24	0,91	0,93	0,15	0,19	0,93	0,95	0,22	0,27	0,89	0,92
C_{13}	0,28	0,35	0,83	0,87	0,26	0,32	0,85	0,89	0,25	0,31	0,86	0,89	0,12	0,15	0,94	0,96	0,14	0,17	0,93	0,95
C_{21}	0,30	0,37	0,73	0,79	0,30	0,37	0,73	0,79	0,27	0,34	0,75	0,81	0,53	0,63	0,47	0,58	0,12	0,19	0,87	0,92
C_{22}	0,24	0,29	0,85	0,88	0,26	0,31	0,83	0,87	0,19	0,24	0,88	0,91	0,31	0,38	0,78	0,83	0,31	0,38	0,78	0,83
C_{31}	0,18	0,22	0,92	0,94	0,20	0,25	0,91	0,93	0,23	0,29	0,89	0,92	0,06	0,08	0,98	0,98	0,09	0,12	0,96	0,97
C_{32}	0,14	0,17	0,95	0,96	0,19	0,23	0,92	0,94	0,16	0,20	0,94	0,95	0,04	0,07	0,98	0,99	0,13	0,16	0,95	0,97
C_{33}	0,27	0,33	0,79	0,84	0,33	0,40	0,73	0,79	0,47	0,58	0,57	0,67	0,10	0,15	0,92	0,95	0,26	0,32	0,80	0,84
C_{34}	0,15	0,18	0,94	0,95	0,20	0,25	0,90	0,93	0,11	0,13	0,96	0,97	0,15	0,19	0,94	0,95	0,07	0,10	0,97	0,98
C_{41}	0,09	0,11	0,98	0,98	0,10	0,12	0,98	0,98	0,10	0,13	0,97	0,98	0,08	0,09	0,98	0,99	0,09	0,11	0,98	0,98
C_{42}	0,09	0,11	0,98	0,98	0,12	0,15	0,96	0,97	0,10	0,12	0,97	0,98	0,16	0,20	0,94	0,96	0,11	0,14	0,97	0,97
C_{43}	0,18	0,22	0,92	0,94	0,18	0,22	0,92	0,94	0,11	0,14	0,95	0,96	0,24	0,29	0,88	0,91	0,12	0,16	0,95	0,96

Table C.4. WSM Values for Each Alternative

A1				A2				A3				A4				A5			
μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
0,627	0,734	0,249	0,353	0,661	0,765	0,218	0,319	0,671	0,773	0,207	0,318	0,673	0,782	0,214	0,326	0,529	0,636	0,358	0,471

Table C.5. Calculation of WPM

WPM	A1				A2				A3				A4				A5			
($r_{ij} \wedge w_j$)	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U	μ_L	μ_U	v_L	v_U
C ₁₁	0,991	0,994	0,032	0,047	0,995	0,997	0,014	0,027	0,990	0,993	0,038	0,05	0,981	0,986	0,070	0,090	0,980	0,985	0,074	0,095
C ₁₂	0,989	0,994	0,021	0,040	0,977	0,985	0,054	0,077	0,982	0,989	0,040	0,063	0,972	0,980	0,068	0,093	0,986	0,992	0,028	0,049
C ₁₃	0,986	0,993	0,021	0,044	0,982	0,990	0,030	0,055	0,980	0,989	0,035	0,060	0,937	0,953	0,131	0,167	0,947	0,961	0,111	0,145
C ₂₁	0,807	0,857	0,209	0,273	0,807	0,857	0,209	0,273	0,785	0,838	0,233	0,301	0,936	0,967	0,050	0,097	0,625	0,708	0,393	0,486
C ₂₂	0,947	0,964	0,083	0,118	0,954	0,970	0,070	0,103	0,927	0,947	0,118	0,158	0,970	0,983	0,041	0,070	0,970	0,983	0,041	0,070
C ₃₁	0,986	0,991	0,036	0,056	0,989	0,994	0,024	0,044	0,992	0,997	0,014	0,032	0,946	0,959	0,137	0,172	0,964	0,973	0,098	0,125
C ₃₂	0,987	0,991	0,038	0,056	0,993	0,997	0,016	0,032	0,991	0,995	0,025	0,042	0,955	0,966	0,126	0,159	0,985	0,990	0,045	0,064
C ₃₃	0,885	0,917	0,150	0,200	0,917	0,944	0,103	0,150	0,963	0,984	0,031	0,069	0,727	0,791	0,334	0,413	0,878	0,911	0,159	0,211
C ₃₄	0,979	0,985	0,054	0,076	0,989	0,994	0,023	0,042	0,967	0,976	0,086	0,112	0,980	0,987	0,050	0,071	0,952	0,964	0,118	0,151
C ₄₁	0,995	0,997	0,021	0,032	0,996	0,998	0,017	0,027	0,997	0,998	0,013	0,023	0,994	0,996	0,029	0,041	0,996	0,997	0,019	0,029
C ₄₂	0,985	0,989	0,055	0,073	0,991	0,994	0,030	0,046	0,988	0,991	0,046	0,062	0,995	0,998	0,012	0,025	0,990	0,993	0,036	0,052
C ₄₃	0,976	0,984	0,053	0,078	0,976	0,984	0,053	0,078	0,954	0,966	0,105	0,136	0,987	0,993	0,024	0,044	0,959	0,970	0,094	0,123

Table C.6. WPM Values of Each Alternative

A1				A2				A3				A4				A5			
μ L	μ U	vL	vU	μ L	μ U	vL	vU	μ L	μ U	vL	vU	μ L	μ U	vL	vU	μ L	μ U	vL	vU
0,595	0,698	0,290	0,388	0,631	0,733	0,259	0,354	0,596	0,701	0,304	0,399	0,509	0,625	0,414	0,517	0,416	0,531	0,470	0,582

CURRICULUM VITAE

Personal Information:

Name - Surname:

Şenay KOMA

Education:

1997-2001 BA in Industrial Engineering, Yıldız Technical University, Türkiye

2001-2004 MA in Industrial Engineering, Yıldız Technical University, Türkiye

2020-2022 MA in Air Transport Management, Ibn Haldun University, Türkiye

Experience:

2016-Today Turkish Airlines Inc.

2009-2016 Turkish Ground Service