A PROPOSED METHOD FOR AIRCRAFT SELECTION USING INTERVAL-VALUED SPHERICAL FUZZY ANALYTIC HIERARCHY PROCESS
(ARALIK DEĞERLİ KÜRESEL BULANIK ANALİTİK HİYERARŞİ YÖNTEMİ İLE UÇAK SEÇİMİ)

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LIST OF SYMBOLS

AHP : Analytical Hierarchy Process
ASK : Available Seat Kilometer
CFRP : Carbon Fiber Reinforced Plastic
CR : Consistency Ratio
DM : Decision Maker
HFSs : Hesitant Fuzzy Sets
GRA : Grey Relational Analysis
IATA : International Air Transport Association
ICAO : International Civil Aviation Organization
IFSs : Intuitionistic Fuzzy Sets
IVFSs : Interval-valued Fuzzy Sets
IVSFSs : Interval- Valued Spherical Fuzzy Sets
MCDM : Multi Criteria Decision Making
MTOW : Maximum Take-Off Weight
NB : Narrow-body
NSs : Neutrosophic Sets
PFSs : Pythagorean Fuzzy Sets
RPK : Revenue Passenger Kilometer
SAF : Sustainable Aviation Fuel
SFSs : Spherical Fuzzy Sets
SFAHP : Spherical Fuzzy Analytical Hierarchy Process
TOPSIS : Technique for Order Preference by Similarity to Ideal Solution
WB : Wide-body

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ABSTRACT

The aviation industry plays a crucial role in global connectivity, economic development, and transportation efficiency. It provides numerous advantages such as speed, comfort, reliability and network. As a result of this, there is an increasing demand for air transportation not only in terms of passenger but also in terms of logistics which creates a competitive environment in the industry. Airline companies are willing to enhance their fleet to meet this thriving demand. Therefore, fleet planning and aircraft selection are crucial issues to be managed by airline firms.

The aircraft selection is a complex decision-making process containing multiple criteria and uncertainties. In other words, fleet planning experts should analyze aircraft types under vagueness based on different criteria to select the most appropriate one that best suits the company's needs.

This paper's objective is to develop structured framework for aircraft selection considering three main categories which are financial, technical and environmental aspects and twelve sub-criteria under fuzziness and vagueness. Traditional decision-making methods frequently fail to address the ambiguities and imprecisions inherent in aircraft selection. In response to this challenge, this study presents a novel approach for aircraft selection based on the Interval Valued Spherical Fuzzy Analytic Hierarchy Process (IVSFAHP). The proposed method allows decision-makers to express their preferences in the form of linguistic terms, which are then transformed into interval valued spherical fuzzy numbers. These fuzzy numbers are utilized to derive the weights of criteria and the performance ratings of alternatives in a comprehensive and systematic manner.

To validate the effectiveness and applicability of the proposed method, a case study is conducted to address the problem of selecting aircraft for a private company. Three decision makers evaluated 5 aircraft alternatives under different criteria. According to the result, A350-900 is selected as the most suitable alternative for the company's needs. This study makes a valuable contribution to the field of aviation management by providing a robust and flexible approach to aircraft selection and helps high-level executives to make appropriate decision among different alternatives by considering necessary conditions to align with organizational target and industry standards.

Keywords: Aircraft Selection, Fuzzy Multi-Criteria Decision Making, AHP, Spherical Fuzzy Sets, Fleet Selection

ÖZET

Havacılık endüstrisi küresel bağlantı, ekonomik kalkınma ve ulaşım verimliliğinde çok önemli bir rol oynamaktadır. Hız, konfor, güvenilirlik ve ağ gibi birçok avantaj sağlamaktadır. Bunun sonucunda sadece yolcu açısından değil lojistik açıdan da hava taşımacılığına olan talep giderek artmakta ve bu da sektörde rekabet ortamı yaratmaktadır. Havayolu şirketleri bu artan talebi karşılamak için filolarını genişletmeye ihtiyaç duymaktadırlar. Bu nedenle filo planlaması ve uçak seçimi havayolu firmalarının yönetmesi gereken önemli konular arasındadır.

Uçak seçimi, birden fazla kriter ve belirsizlik içeren karmaşık bir karar verme sürecidir. Filo planlama uzmanlarının belirsizlik altındaki uçak tiplerini farklı kriterlere göre analiz ederek şirketin ihtiyaçlarına en uygun olan uçağı seçmesi gerekmektedir.

Bu çalışmanın amacı, bulanıklık ve belirsizlik altında finansal, teknik ve çevresel boyutlar olmak üzere üç ana kategoriyi ve oniki alt kriteri dikkate alarak uçak seçimi yapmaktır. Geleneksel karar verme yöntemleri sıklıkla uçak seçiminin doğasında olan belirsizlikleri gidermede başarısız olmaktadır. Buna karşın bu çalışma, uçak seçimi için Aralık Değerli Küresel Bulanık Analitik Hiyerarşi Sürecini (IVSFAHP) kullanarak yeni bir yaklaşım sunmaktadır. Önerilen yöntem, karar vericilerin tercihlerini dilsel terimler biçiminde ifade etmelerine olanak tanımakta ve bunlar daha sonra aralık değerli küresel bulanık sayılara dönüştürülmektedir. Bu bulanık sayılar, kriterlerin ağırlıklarını ve alternatiflerin performans derecelerini kapsamlı ve sistematik bir şekilde elde etmek için kullanılmaktadır.

Önerilen yöntemin etkinliğini ve uygulanabilirliğini doğrulamak amacıyla özel bir şirket için uçak seçimini içeren bir örnek olay çalışması yapılmıştır. Üç karar verici, verilen kriterler kapsamında 5 uçak alternatifini değerlendirmiştir. Çıkan sonuca göre firmanın

ihtiyaçlarına en uygun alternatif olarak A350-900 seçilmiştir. Bu çalışma, uçak seçimine sağlam ve esnek bir yaklaşım sunarak havacılık yönetimi alanına değerli bir katkı sağlamakta ve üst düzey yöneticilerin organizasyonel hedef ve endüstri standartlarına uyum için gerekli koşulları göz önünde bulundurarak farklı alternatifler arasından uygun karar vermelerine yardımcı olmaktadır.

Anahtar Sözcükler: Uçak Seçimi, Çok Kriterli Karar Verme, Analitik Hiyerarşi Süreci, Küresel Bulanık Kümeler, Filo Planlama

1.INTRODUCTION

The aviation industry plays a crucial role and function in connecting people and goods all around the world, promoting tourism and facilitating international trade. The industry progresses through technological advancements, adjusts to evolving market conditions, and emphasizes sustainability.

In recent years, the air transportation industry has a growing trend both in passenger and cargo transportation. Even though Covid-19 has damaged this industry profoundly, there is a recovery in passenger and increase in air cargo transportation. In 2021, there has been a 49% (ICAO, 2022) decline in total number of passengers while the air cargo has increased by 6.9% (IATA, 2021) compared to 2019. The figure 1.1 displays the world passenger traffic annually and the dramatic decline due to Covid-19 compared to previous years. According to Airbus' Global Market Forecast (2022(a)), the passenger traffic and freight traffic will rise by 3.6% and 3.2% respectively. This increasing demand is creating a competitive market in the industry. As a result of this, airline firms should make their decisions professionally to become successful in this competitive environment.

The fleet planning is a critical issue and long-term strategy for airlines to meet the demand and gain competitive advantage. Since there are many criteria to take into consideration while choosing an aircraft among various aircraft alternatives, it is very significant for an airline company to find a way for choosing the best aircraft among these alternatives.
Multi- Criteria Decision Making (MCDM) is a procedure to assist decision makers to come up with an appropriate consequence among different alternatives to solve a given problem. Fuzzy set theory is beneficial in appraising the vagueness and uncertainty in decision maker's verdict (Zadeh, 1965). The proposed MCDM methods will help decision makers to evaluate alternatives by handling this ambiguity.

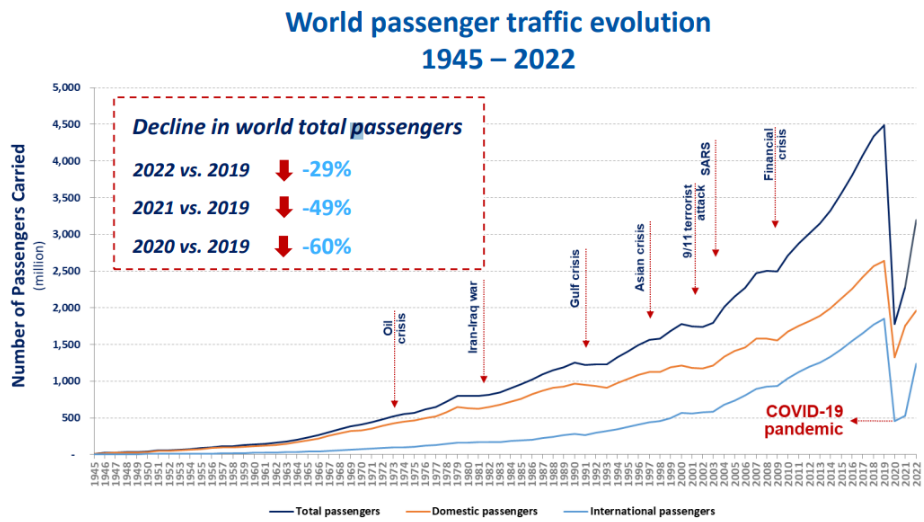


Figure 1.1 The world annual passenger traffic (ICAO,2022)

In 1950s, MCDM methods were developed to assist airline planners for selecting aircrafts. Planners strive to select the best alternative among many aircrafts considering many different criteria (Bakır et al., 2018). Numerous techniques were used in the evaluation process and MCDM methods provided convincing solutions for selecting aircraft (Dozic et al., 2018).

There are several MCDM techniques. In this paper, one of them which is interval-valued spherical fuzzy Analytic Hierarchy Process (IVSAHP) method is used in order to select the best aircraft alternative. Saaty (1980) pioneered the Analytic Hierarchy Process (AHP), wherein a problem is organized hierarchically, starting from a goal down to criteria, sub-criteria, and subsequent levels. The hierarchical structure provides decision-makers with a comprehensive perspective on the intricate relationships inherent in the problem. It helps them assess whether elements at the same level are comparable. Elements are confronted using 9-level scales to determine their weights. However, pairwise comparison brings nebulousness due to the fact that it needs the judgements of experts (Liu et al., 2020). In numerous practical scenarios, decision-makers may encounter challenges in assigning precise numerical values to their preferences (Chan & Kumar, 2007). Hence, in AHP, the fuzzy numbers are employed to express each judgement made in pairwise comparison (Xu & Liao, 2014).

The purpose of this study is choosing a suitable aircraft among different alternatives for an airline company in Türkiye. The motivations behind this study are that there is an increasing passenger and air cargo demand which creates the necessity of expanding fleet and since there will be many vagueness during decision process, this study will help firms to make their decision in a professional way. Also, this paper will use the interval-valued spherical fuzzy AHP for selecting aircraft which is never applied in literature before.

The structure of this paper is outlined as follows: Section 2 ensures overview of air transportation. Section 3 delves into the details of fleet planning. Section 4 consists of literature review on selecting aircraft by using MCDM techniques. Section 5 explains the details of the proposed methodology. Section 6 clarifies applying the MCDM technique on a case study with numerical example. Section 7 and 8 ensures an outline of the results and sensitivity analysis, respectively. Eventually, Section 9 provides the conclusion.

2. AIR TRANSPORTATION

2.1 Transportation

Transportation is a Latin origin word, formed by a combination of trans (across) and portate (to carry) which means to carry across or to convey from one point to another. Transportation involves the transfer of people, animals, commodities, or substances from one place to another. It is utilized for facilitating trade, ensuring the communication, and exchanging of goods and services. It is an essential element that provides inter-societal and intercultural interaction by connecting different societies socially, economically and culturally (Güntut, 2019). There are various modes of transportation to move people or goods safely such as road transportation, maritime transportation, rail transportation and air transportation.

2.1.1 Road Transportation

Road transportation is movement of passenger or freight from one location to another location on the surface of land using various vehicles and infrastructure. The road transportation can be done by cars, buses, motorcycles and trucks. It is the cheapest mode of transportation. It is economically viable for short distance and the core lifeline of the logistics as it ensures door to door service. However; it is not suitable for long distance transports and heavy cargo. It has a high risk of goods being damaged. Traffic and adverse weather conditions such as floods are known to hinder road transportation.

2.1.2 Rail Transportation

Rail transportation is moving the passengers or goods on railways by using trains. It offers faster transportation compared to road transportation. Rail transport provides transportation of large volume of freight and is suitable for long distance. It is concerned as green with its lower greenhouse gas emissions. It is less affected by adverse weather conditions and traffic restrictions (Akoğlu, 2020). However; having fixed network and high initial cost of building rail infrastructure can be seen as disadvantages of rail transportation.

2.1.3 Maritime Transportation

Maritime transportation is carrying people or commodities by ships and vessels over oceans, sea and rivers. It has significant role in international trade. It is ideal for long-distance travel and can carry a wide range of freight types. It provides high capacity for carrying a massive amount of cargo. However; it has longer transit times, it can be affected by weather conditions and the maintenance cost of ships are high.

2.1.4 Air Transportation

Air transportation is one of the fastest and safest transportation modes. It provides numerous opportunities such as speed, comfort, safety, service quality, and wide network. Therefore, it has an increasing demand compared to other modes.
Passengers mostly prefer air transportation for its speed, comfort and reliability. The strict safety regulations and using advanced technology in aircraft make air travel more reliable. Since airlines offer in-flight entertainment, comfortable seats and meal options, it is more attractive to people.

Air transportation takes priority when an urgent delivery is required and costs remain in the background. It is a type of transportation suitable for items that are low in terms of volume and weight but high in terms of value. High speed, adequate frequency and low probability of damage to the goods are the advantages of this transportation (Suvacı, 2013).

Air passenger traffic had a growing trend until 2020 pre-Covid term as it is shown in figure 2.1. Pandemic had a profound impact on aviation industry. Due to travel restrictions and quarantine measures, airlines faced a massive decrease in the number of passengers and flights were cancelled. In 2021, the global passenger traffic had decreased approximately by 50% compared to pre-Covid term. After the easing the restrictions, flights resumed and total passenger traffic increased by 22.4% in 2021 compared to 2020. On the other hand, air cargo transportation played a crucial role during the pandemic era by carrying medical supplies, vaccines, and essential pharmaceutical goods. Some airlines focused on cargo operations during this time to compensate the passenger revenue loss. According to ICAO (2021), the total freight carried increased by 19.3% in 2021 compared to 2020 as it is shown in figure 2.2.

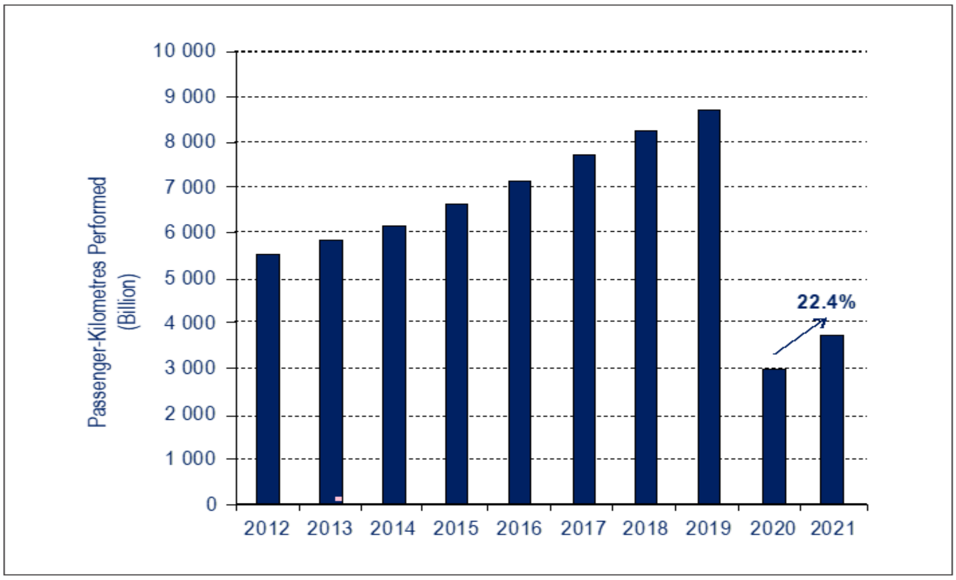


Figure 2.1 Total scheduled passenger traffic (ICAO,2021)

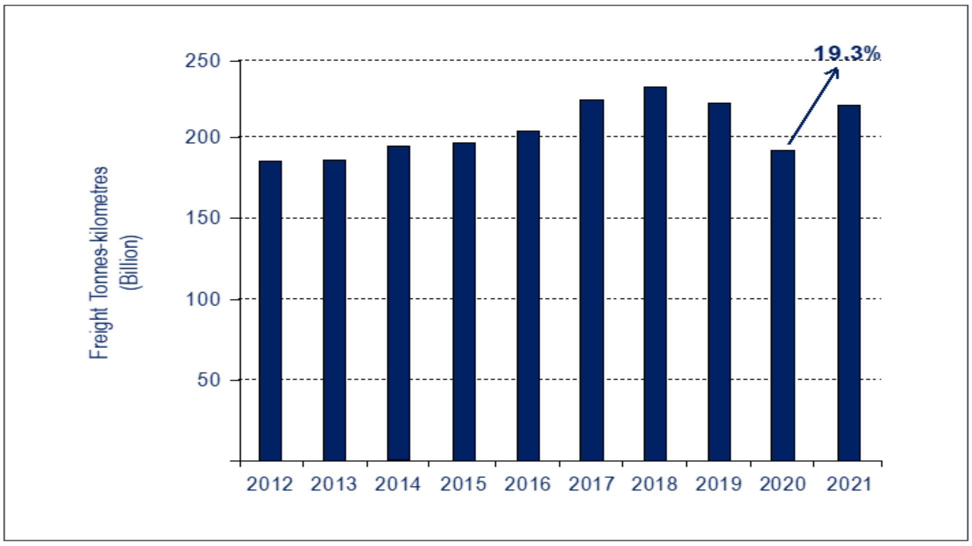


Figure 2.2 Total freight traffic (ICAO,2021)

3. FLEET PLANNING

Airlines are complicated organizations dealing with moving people and goods daily from one point to another. The air transportation industry aims to ensure time, safety and comfort advantages to passenger for transporting them to their requested destinations. To achieve this goal, airlines need high amount of capital. The aircrafts in an airline company's fleet constitute by far the largest investment category.

Fleet planning is a crucial process which is managed and acquired by airlines that contains making strategic decisions about the composition and the size of an airline's fleet in order to adapt to changing market demands and maximize company's value. In the aviation industry, effective fleet planning is significant for providing profitability, competitiveness and operational efficiency.

It is very important for an airline company to be able to choose the appropriate aircraft in order to continue its operations profitably and expand its market share. During fleet planning process, airline companies should consider factors such as target market, passenger profile, operational constraints, and financial status. They need to evaluate the future industry trends, the economic structure of the company, potential new routes to be flown in order to create optimal fleet (Yılmaz, 2006).

A multidisciplinary approach containing specialty in finance, engineering, operations, and market analysis is necessary for fleet planning. Throughout this process, it is essential to address topics meticulously regarding the ideal number of aircraft, the selection of appropriate aircraft types, strategic acquisition time, retirement planning, and the careful deliberation between leasing and purchasing options (Güntut, 2019). A proper fleet planning process is essential for airlines to make long-term strategic decisions effectively.

Inputs from many sources such as traffic forecasts, operating costs, profit estimates and estimated aircraft productivity are required in fleet planning. These estimations are acquired from various databases from different departments and the airline planning process is idealized by these estimations (Belobaba, 2016). Figure 3.1 shows the airline planning process.

Figure 3.1. The airline planning process (Belobaba,2015)

During the fleet planning process, the airline company should analyze the market and forecast the expected traffic, expressed in revenue passenger kilometer (RPK), to obtain the future growth of routes and regions. After forecasting the RPK, average load factor is used to obtain the future ASK (available seat kilometer). ASK is calculated by the dividing the forecasted RPK by the average load factor. The number of required aircraft to meet the forecasted future ASK can be calculated by making assumptions regarding the aircraft type's productivity, measured in its capacity to generate ASKs on a daily, monthly, or yearly basis. The number of aircrafts to be obtained has financial effects such as depreciation, investment funding, operating cost and interest expenditure. The operating cost required to be forecasted as well. The calculation of revenues that will be obtained by operating the new aircraft is based on the forecast of both the traffic and the yield (per RPK). Combining the revenue forecast with operating cost forecast gives the opportunity to the airline companies for determining operating profit estimates or targets (Belobaba, 2016).

The other concern is deciding the way to obtain the required aircraft after estimating the revenue and operating cost. There are two ways to acquire a new aircraft which are purchasing aircraft and leasing aircraft.

- Purchasing an aircraft

  The airline company add the aircraft to its fleet by purchasing it directly from the aircraft manufacturer under the negotiations and the agreements.

- Leasing

  There are two types of leasing which are wet leasing and dry leasing.

  Wet leasing is a method in which an airline (the lessee) leases the aircraft from another airline (the lessor) ensuring complete crew, insurance and maintenance. The lessor operates the aircraft by providing crew and maintaining the aircraft. The lessee, on the other hand, provides fuel, sells the tickets and obtains flight schedule.

  On the other hand, dry lease is a method in which an airline leases the aircraft from a lessor without crew, maintenance and insurance. Airline operates the aircraft by its own crew, ensures insurance and maintains the aircraft.

Fleet planning requires an attentive balance between financial situation, market demands, operational efficiency and sustainability. Airlines continuously follow dynamic market trends and technological developments in order to create right fleet strategies to adapt the changing environment quickly.

4. LITERATURE REVIEW

Numerous studies in the literature focus on choosing the most suitable aircraft among various alternatives, employing different MCDM methods based on specific criteria.

Yeh and Chang (2009) introduced a novel fuzzy MCDM algorithm to address the aircraft selection issue for a domestic airline in Taiwan. They defined three main criteria which are technological advance, social responsibility and economic efficiency and eleven sub-criteria. The proposed algorithm assesses and evaluates the alternatives which are B757-200, A321, B767-200, MD-82, and A310-300. Triangular fuzzy numbers are used to aggregate individual judgements as group judgement in order to handle subjective imprecision. Eight decision makers are involved in the assessment. The adjusted TOPSIS approach was employed to rank the alternatives with criteria weights that are involved in the distance measurement for weighting the distance between the alternative and positive or negative ideal solution. Following the evaluation, the algorithm ranks B757-200 as the top choice.

Özdemir et al. (2011) used Analytic Network Process (ANP) to evaluate the aircraft alternatives for Turkish Airlines. In ANP, the weighted supermatrix and limit supermatrix are constructed after the interactions between criteria, sub-criteria and alternatives are defined. Authors determined three main criteria which are cost, time and physical attributes and compared three alternatives which are A319, A320 and B737. As a result of applying the method, B737 is seemed to be more feasible to purchase.

Sun et al. (2011) utilised three MCDM methods namely Elimination and Choice Expressing Reality (ELECTRE), simple additive weighting (SAW) and TOPSIS to address an aircraft selection problem for a hypothetical airline. The author introduced robustness as an additional decision criterion. The study incorporated the use of the

Taguchi loss function to handle economic uncertainties. Three different aircraft types are evaluated under six criteria. B747-400 was identified as the most suitable aircraft.
Gomes et al. (2014) used NAIDE (Novel Approach to Imprecise Assessment and Decision Environments) method to solve the problem of investing in regional charter flights in Brazil. The authors divided the main criteria as financial, logistics and quality which have several sub-criteria such as operating cost, range, safety. LET-410 is chosen as the best alternative.

The AHP method was utilised by Dozic and Kalic (2014) for the election of passenger aircraft. A logarithmic fuzzy preference programming (LFPP) method was utilised in order to derive crisp priorities from fuzzy pairwise comparison. With considering three criteria and ten sub-criteria, seven alternatives were appraised. CRJ 700 is chosen as the best option among others.

Bruno et al. (2015) used both AHP and Fuzzy Set Theory to select aircraft in order to support strategic decisions of airlines. Economic performance, technical proficiency, the quality of aircraft interior and environmental impact are formed as the main criteria. Three aircrafts are evaluated by the proposed methods in a case study for Air Italy. Four experts from Air Italy evaluated the importance of each criterion. According to the results, the aircraft type with the highest evaluation score became the Sukhoi SSJ 1000.

Dožić and Kalić (2015) compared two methods that are the Analytic Hierarchy Process (AHP) and the Even Swaps Method (ESM) for aircraft selection problem. The decision criteria are selected as number of seats, aircraft purchase price, baggage capacity, maximal take-off mass, payment requirements. The most suitable aircraft was ATR72-600 according to ESM. AHP was sensitive to changes in criteria while ESM was not sensitive.

Özdemir and Başlıgil (2016) utilised fuzzy ANP and the generalized choquet integral method for choosing an appropriate aircraft. Fuzzy AHP was used to compare the results. Choquet integral can be defined as a general averaging operator which indicates the interactions among criteria. In Choquet integral method, the trapezoidal fuzzy numbers are utilised in order to quantify linguistic terms and make comparisons with experts. The main criteria were defined as cost, physical features and time and three alternatives are evaluated. The fuzzy ANP and Choquet integral method have determined same result. Bakır and Kiracı (2018) used TOPSIS method to find the right aircraft. TOPSIS is a technique where the chosen alternative is closest to the positive ideal solution and farthest from the negative ideal solution. Positive ideal solutions encompass the optimal values for all criteria, while negative ideal solutions comprise the worst values for the criteria. They defined the criteria as range, price, speed, passenger capacity, fuel consumption. Four alternatives were evaluated and the result showed that B737-800 became the convenient aircraft.

İlgin (2019) proposed Linear Physical Programming (LPP) method and TOPSIS in order to evaluate different aircrafts. In TOPSIS, the ranking is based on criteria weights which are assigned by decision makers subjectively. In LPP, however, subjective weighting is eliminated and the ambiguity of DMs' preferences is not considered. The author evaluated six aircraft alternatives under five criteria which are price, fuel consumption, range, seat capacity and luggage volume. The ranking results from TOPSIS and LPP were same and A321 (neo) ranked as first.

Şener and Yılanlı (2020) used Decision Making Trial and Evaluation Laboratory (DEMATEL) method in order to get the effectiveness of criteria. The fourteen criteria were determined and the comparison in pairs was conducted. Then, the DMs identified their effects. Four alternatives were evaluated.

Ardil (2020) used Process Using Preference Analysis for Reference Ideal Solution (PARIS) method and the TOPSIS method to evaluate the different types of passenger aircrafts and come up with an appropriate one which is A312 (neo). The six alternatives were examined considering criteria such as aircraft price, aircraft fuel consumption, aircraft's seat number and luggage volume.

AHP and TOPSIS in interval type-2 fuzzy sets (IT2F) were used by Akan and Kiracı (2020) for selecting of commercial aircraft. IT2FAHP was utilised to compute the weight of criteria for IT2FTOPSIS method in which the aircraft alternatives were ranked. Four aircrafts with short and medium ranges were examined with three main criteria which are

economic performance, technical performance and environmental impact and eight sub-criteria. A321neo is the most suitable aircraft alternative according to result.
Ahmed et al. (2020) proposed integrated framework of fuzzy Analytic Hierarchy Process (FAHP) and Efficacy Method to evaluate aircraft alternatives for Canada's regional operations. FAHP was used to define the weight of selected criteria by covering all ambiguity. The weight of criteria was then used for determining the total efficacy co-efficient. Purchasing cost, seat capacity, range, payload and carbon monoxide were determined as criteria. ARJ21-700 was selected as a suitable aircraft.

Akyurt and Kabadayı (2020) used fuzzy AHP and fuzzy grey relational analysis (GRA) method for selecting the best cargo aircraft. The fuzzy GRA method is advantageous for solving problems since it can provide successful results even when relatively little data is available or there is a large amount of variability between criterions. The fuzzy AHP method was utilized for calculating the weights of values that define the importance of the criteria. The most appropriate aircraft was chosen by the fuzzy GRA method using the criteria weights which were defined by the fuzzy AHP method. Main criteria were specified as cost, operational compatibility and time. Each main criteria divided into fifteen sub-criteria in total. B777F, A330-200F, B747-400F and A310-300F were selected as alternatives. After the methodology was applied, B777F got the highest grey relational degree and was resulted as the most suitable aircraft among other alternatives.

Bakır et al. (2021) employed integrated fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA) and fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (F-MARCOS) to select the appropriate regional aircraft. In the study, six aircraft alternatives were examined under fourteen criteria. Operational cost emerged as the foremost criterion, while nitrogen oxide emission (NOx) was identified as the least significant. The PIPRECIA is an advantageous approach for group decisions with large number of decision makers and criteria. With F-PIPRECIA, the weights of criteria were found and with F-MARCOS, the alternatives were ranked by utilising the criteria weights. CRJ1000 was selected the most appropriate aircraft.

Deveci et al. (2022) proposed Entropy-based Weighted Aggregated Sum Product Assessment (WASPAS) method in order to detect appropriate aircraft for a given route between Kuwait and İstanbul. Authors proposed this method in order to find the suitable way to derive the weight vector and aggregate the DM’s preferences. The five main criteria of profit, capacity, customer expectancy, expenditure and competition were selected with ten sub-criteria. The evaluation showed that Airbus32C should be selected for this route.

Kartal (2022) proposed Step-wise Weight Assessment Ratio Analysis (SWARA) based EDAS and COPRAS methods in order to evaluate both narrow-body and wide-body passenger aircraft preferred by airlines. Six criteria have been determined, including purchase cost, fuel capacity, maximum seat capacity, range, maximum take-off weight and cargo capacity. 7 passenger narrow body and 9 passenger wide body alternatives were taken into consideration. In the study, ten experts including of academicians with aviation industry experience filled a SWARA questionnaire. The experts ranked the criteria according to their own priorities and then assign the pertinent importance values for the criteria with respect to the order they obtained. SWARA method was applied to the data obtained from each expert in order to get the criteria weights. Then, the averages of the criteria weights defined by ten experts were taken and the final weights were calculated for each criterion. After the criterion weights were determined, rankings were obtained by applying EDAS and COPRAS methods for both narrow body and wide body passenger aircraft. As a result of this study, the A321neo aircraft for narrow body passenger aircraft and the A350-1000 aircraft for wide body aircraft were obtained as the best alternative by both EDAS and COPRAS methods.

Through extensive literature review, it has been determined that MCDM methods are suitable for addressing the passenger aircraft selection problem. In the literature, fuzzy AHP method was mostly utilized technique to address the issue of choosing aircraft. To the best of our knowledge, this is the first study that used IVSFAHP method in aircraft selection process. IVSF numbers ensure a richer representation of linguistic terms and fuzzy preferences compared to fuzzy AHP method. This representation allows decision-makers to express their preferences in a more flexible way.

Table 4.1. Literature review

Author(s)	Article Name	MCDM Method(s)	Year
Yeh & Chang	Modeling Subjective Evaluation for Fuzzy Group Multicriteria Decision Making	The modified TOPSIS	2009
Özdemir et al.	Aircraft Selection Using Analytic Network Process: A Case for Turkish Airlines	Analytic Network Process (ANP)	2011
Sun et al.	Robustness Consideration in Multi-Criteria Decision Making to an Aircraft Selection Problem	Elimination and Choice Expressing Reality (ELECTRE), simple additive weighting (SAW) and TOPSIS	2011
Gomes et al.	A fuzzy stochastic approach to the multicriteria selection of an aircraft for regional chartering	NAIDE (Novel Approach to Imprecise Assessment and Decision Environments)	2014
Dozic & Kalic	An AHP approach to aircraft selection process	AHP Method	2014
Bruno et al.	A model for aircraft evaluation to support strategic decisions	AHP and Fuzzy Set Theory	2015
Dožić & Kalić	Comparison of two MCDM methodologies in aircraft type selection problem	Analytic Hierarchy Process (AHP) and the Even Swaps Method (ESM)	2015
Özdemir & Başlıgil	Aircraft selection using fuzzy ANP and the generalized choquet integral	Fuzzy ANP and the Generalized Choquet Integral Method	2016
Bakır & Kiracı	Using the Multi Criteria Decision Making Methods in Aircraft Selection Problems and an Application	TOPSIS	2018
İlgin	Aircraft Selection Using Linear Physical Programming	Linear Physical Programming (LPP) and TOPSIS	2019
Şener & Yılanlı	Aircraft Selection in Airline Fleet Management	Decision Making Trial and Evaluation Laboratory (DEMATEL)	2020
Ardil	Aircraft Selection Process Using Preference Analysis for Reference Ideal Solution (PARIS)	Process Using Preference Analysis for Reference Ideal Solution (PARIS) and TOPSIS methods	2020
Akan & Kiracı	Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets	AHP and TOPSIS in interval type-2 fuzzy sets (IT2F)	2020
Ahmed et al.	Regional aircraft selection integrating fuzzy analytic hierarchy process (FAHP) and efficacy method	Fuzzy Analytic Hierarchy Process (FAHP) and Efficacy Method	2020
Akyurt and Kabadayı	Fuzzy AHP and Fuzzy Grey Relational Method for Cargo Aircraft Type Selection: A Case Study in a Turkish Airline Company	Fuzzy AHP and Fuzzy Grey Relational Method	2020
Bakır et al.	Regional Aircraft Selection with Fuzzy Piprecia and Fuzzy Marcos: A Case Study of the Turkish Airline Industry	Integrated Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA) and Fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (F-MARCOS)	2021
Deveci et al.	Interval type-2 hesitant fuzzy Entropy-based WASPAS approach for Aircraft Type Selection	Entropy-based Weighted Aggregated Sum Product Assessment (WASPAS)	2022
Kartal	Use of Swara-based EDAS and COPRAS Methods in Aircraft Selection Strategy for Airlines	Step-wise Weight Assessment Ratio Analysis (SWARA) based EDAS and COPRAS methods	2022

5. METHODOLOGY

In this part, the details of the MCDM, the conventional AHP, the mathematical operations of interval – valued spherical fuzzy sets (IVSFS) and the proposed interval-valued spherical fuzzy AHP method are explained thoroughly.

5.1 Multi Criteria Decision Making – General Overview

Decision-making (DM) is a procedure of selecting a convenient option among two or more alternatives of an action. It's a fundamental cognitive practice that individuals, groups and organizations encounter regularly. The fundamental steps of decision-making are identifying the problem, collecting information, evaluating alternatives, considering potential outcomes, and ultimately making a selection based upon available information and personal or organizational targets.

MCDM methods are an operations research sub-branch and mathematical models that use different forms of data and information to solve complex problems with conflicting, multiple objectives and high uncertainty (Wang et al., 2009). The goal of MCDM techniques is to ensure a structured approach to assist DMs to evaluate multiple alternatives in a complex and ambiguous situation.

5.2 Fuzzy Sets and Spherical Fuzzy Sets (SFSs)

Fuzzy sets are a mathematic branch and computational intelligence which cope with decision-making and reasoning under uncertain and vague situations. While in classical (crisp) sets, an element either belongs to a set or it does not, in fuzzy sets, elements have membership degrees between 0-1.

The notion of fuzzy sets was set forth by Lotfi Zadeh in 1965 as a process for formalizing and represent ambiguity and uncertainty in decision-making. According to Zadeh, the status of an element belonging to a set takes a value among 0 and 1.

Zadeh defined the basic features of fuzzy logic as follows (Karataş, 2018):

In fuzzy logic, there is a thinking based on approximate values instead of thinking based on exact reasons.

- In fuzzy logic, all values are indicated with a membership degree from the range [0-1].
- In fuzzy logic, information is defined with linguistic expressions such as very true, true, more or less true, and the fuzzy inference process is carried out with the rules determined between the verbal expressions.
- Every logical system can be fuzzy.
- Fuzzy logic is a very convenient method for systems which has very complex mathematical models that are difficult to obtain.

The regular fuzzy sets which are acquainted by Zadeh were expanded and multiple fuzzy extensions have been created. These extensions are used to deal with MCDM problems in recent years by many researchers (Figure 5.1).

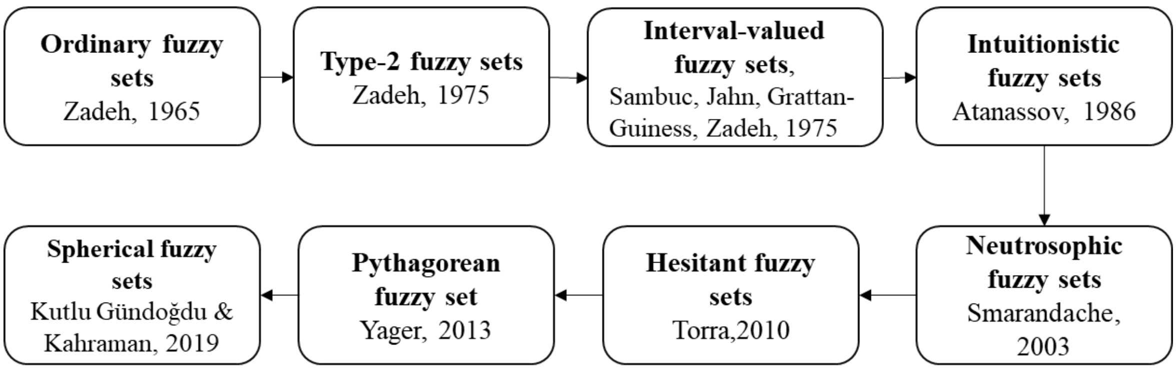


Figure 5.1 Extensions of fuzzy sets (Kutlu Gündoğdu & Kahraman, 2019)

Type-2 fuzzy sets were presented by Zadeh in 1975 as an extension of ordinary fuzzy sets (called "type-1 fuzzy set"). Type-2 fuzzy sets deal with situations where the degree of membership itself is uncertain or fuzzy while type-1 fuzzy sets deal with uncertainty by assigning a degree of membership is a crisp number in the range of [0,1] (Zadeh 1975). Zadeh proposed interval-valued fuzzy sets (IVFSs) which is a special form of Type-2 fuzzy sets in 1975. IVFSs are based on the principle of defining the membership degree by defining lower and upper limits to address the uncertainty regarding the definition process of the membership function.

Atanassov proposed intuitionistic fuzzy sets (IFS) in 1986 in which he added a third parameter, called hesitancy, to better handle uncertainty, imprecision and hesitation in decision-making process (Atanassov ,1986). Also, he contributed intuitionistic fuzzy sets of second type (IFS2) which are described by a degree of membership and a degree of non-membership which satisfy the condition that the sum of the squares of the degree of membership and the degree of non-membership is equal to or less than 1; this is a generalization of IFS (Atanassov, 1999). The third dimension which is hesitancy degree can be calculated by subtracting the square sum of membership degree and non-membership degree from 1 and taking the square root of the result as $\pi_{\tilde{p}}^{2}(u) = \left(1 - \mu_{\tilde{p}}^{2}(u) - v_{\tilde{p}}^{2}(u)\right)^{\frac{1}{2}}$ where $\pi_{\tilde{p}}(u)$ is hesitancy degree, $\mu_{\tilde{p}}(u)$ is membership degree and $v_{\tilde{p}}(u)$ is non-membership degree.

As an extension of IFS, Smarandache created neutrosophic sets (NSs) which include an indeterminacy degree, truthiness degree, and a falsity degree. NSs deal with the hesitancy of the system and also reduce the hesitancy of hesitant information (Smandache, 1999). Torra and Narukawa (2009) proposed Hesitant fuzzy sets (HFSs) allowing DMs to ensure a set of possible values based on the membership function between 0 and 1. The HFSs provide a more precise representation of people's hesitancy over objects compared to the fuzzy sets or its classical extensions (Zhang, 2013).

Yager (2013) proposed Pythagorean fuzzy sets (PFSs) as an extension of IFS, that are characterized by the sum of squares of both membership grade and non-membership grade is less than or equal to 1.

Kutlu Gündoğdu and Kahraman (2019) proposed Spherical Fuzzy Sets (SFSs) which allow decision makers to explain their hesitation in their linguistic decisions on an alternative. In SFS, there are membership, non-membership and hesitancy degrees determining by DMs. The geometric display for IFS, IFS2, NS, and SFS is shown in figure 5.2.

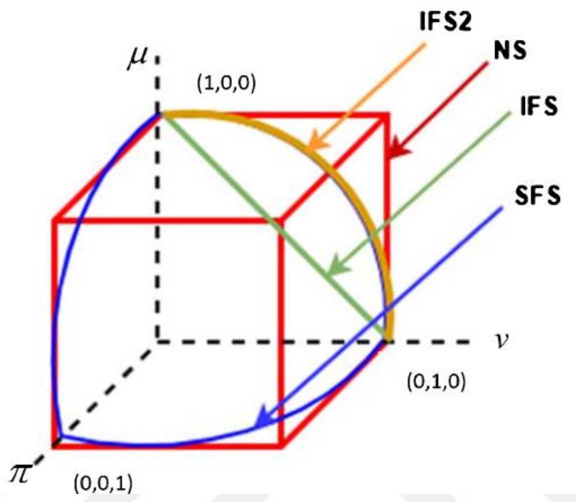


Figure 5.2 Geometric display of IFS, PFS, NS and SFS (Kutlu Gündoğdu & Kahraman, 2019)

SFSs can be used to acquire a more extensive range to determine the membership degrees for criteria and sub-criteria. In SFSs, while the squared sum of membership, non-membership and hesitancy parameters may fall within the range of 0 and 1, each parameter can be independently defined within the range of 0 to 1. SFSs has been developed as an inference of Pythagorean Fuzzy Sets (Kutlu Gündoğdu and Kahraman, 2019). The description of SFSs is defined as follows.

Definition 1: Let X be a universal set, let $\tilde{A}s$ be the single-valued SFS which is described as,

$$\tilde{A}s = \{x, \langle \mu_{\tilde{A}s}(x), v_{\tilde{A}s}(x), \pi_{\tilde{A}s}(x) \rangle | \, x \epsilon X\} \quad (1)$$

Where $\mu_{\tilde{A}s}: X \rightarrow [0,1]$, $v_{\tilde{A}s}: X \rightarrow [0,1]$, $\pi_{\tilde{A}s}: X \rightarrow [0,1]$
and
$0 \leq \mu^2{}_{\tilde{A}s}(x) + v^2{}_{\tilde{A}s}(x) + \pi^2{}_{\tilde{A}s}(x) \leq 1, \forall x \in X. \quad (2)$

Here, $\mu_{\tilde{A}s}(x)$ is the membership degree, $v_{\tilde{A}s}(x)$ is non-membership degree and $\pi_{\tilde{A}s}(x)$ is the degree of hesitancy of u to *Ãs*.

Definition 2: Figure 5.3. displays the geometrical representation of spherical distance among spherical fuzzy sequences which are Ãs and B̃s.

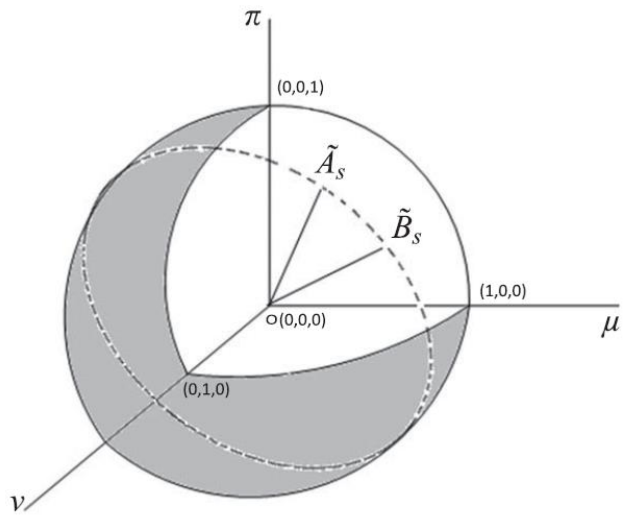


Figure 5.3. Geometric representation of spherical fuzzy sets by Kutlu Gündoğdu & Kahraman, 2019

The formula of spherical distance between Ãs and B̃s on the surface of a sphere is as follows:

$$\text{dis}(\tilde{A}s, \tilde{B}s) = \arccos\left\{ 1 - \frac{1}{2}(\mu_{\tilde{A}s} - \mu_{\tilde{B}s})^2 + (v_{\tilde{A}s} - v_{\tilde{B}s})^2 + (\pi_{\tilde{A}s} - \pi_{\tilde{B}s})^2 \right\} \quad (3)$$

The following statement can be used in order to get the spherical breadth between two spherical fuzzy sequences:

$$\text{dis}(\tilde{A}s, \tilde{B}s) =$$

$$\frac{2}{\pi}\sum_{i=1}^{n} \arccos\left\{ 1 - \frac{1}{2}(\mu_{\tilde{A}s} - \mu_{\tilde{B}s})^2 + (v_{\tilde{A}s} - v_{\tilde{B}s})^2 + (\pi_{\tilde{A}s} - \pi_{\tilde{B}s})^2 \right\} \quad (4)$$

Here, $\frac{2}{\pi}$ is stated to obtain distance values from the range of [0,1] instead of [0,$\frac{\pi}{2}$]. Since $\mu^2{}_{\tilde{A}s}(x) + v^2{}_{\tilde{A}s}(x) + \pi^2{}_{\tilde{A}s}(x) = 1$, we have,

dis(Ãs,B̃s) =

$$\frac{2}{\pi}\sum_{i=1}^{n} \arccos\left(\mu_{\tilde{A}s}(x_i) * \mu_{\tilde{B}s}(x_i) + v(x_i) * v_{\tilde{B}s}(x_i) + \pi_{\tilde{A}s}(x_i) * \pi_{\tilde{B}s}(x_i)\right) \quad (5)$$

The normalization of spherical distance between Ãs and B̃s on the sphere surface:

dis_n(Ãs,B̃s) =

$$\frac{2}{n\pi}\sum_{i=1}^{n} \arccos\left(\mu_{\tilde{A}s}(x_i) * \mu_{\tilde{B}s}(x_i) + v(x_i) * v_{\tilde{B}s}(x_i) + \pi_{\tilde{A}s}(x_i) * \pi_{\tilde{B}s}(x_i)\right) \quad (6)$$

Obviously, we get $0 \leq$ dis(Ãs,B̃s) $\leq$ n and $0 \leq dis_n$(Ãs,B̃s) ≤ 1

5.3 Interval-Valued Spherical Fuzzy Sets – Preliminaries

Kutlu Gündoğdu and Kahraman (2019) designated the arithmetic calculation of IVSFSs. The formulas for defuzzyfying and aggregating IVSFSs are also indicated.

Eq (7) explains an IVSFS $\tilde{A}s$ of the universal set *X*.

$$\tilde{A}s = \left\{ \left(x, \begin{array}{c} [\mu^L{}_{\tilde{A}s}(x), \mu^U{}_{\tilde{A}s}(x)], \\ [v^L{}_{\tilde{A}s}(x), v^U{}_{\tilde{A}s}(x)], \\ [\pi^L{}_{\tilde{A}s}(x), \pi^U{}_{\tilde{A}s}(x)] \end{array} \right) \middle| \, x \epsilon X \right\} \quad (7)$$

Where

$0 \leq \mu^L{}_{\tilde{A}s}(x) \leq \mu^U{}_{\tilde{A}s}(x) \leq 1$,

$0 \leq v^L{}_{\tilde{A}s}(x) \leq v^U{}_{\tilde{A}s}(x) \leq 1$ and

$$0 \leq \left(\mu^{U}{}_{\tilde{A}s}(x)\right)^2 + \left(v^{U}{}_{\tilde{A}s}(x)\right)^2 + \left(\pi^{U}{}_{\tilde{A}s}(x)\right)^2 \leq 1$$

For each $x \epsilon X$, $\mu^{U}{}_{\tilde{A}s}(x)$ is the upper degrees of membership, $v^{U}{}_{\tilde{A}s}(x)$ is the upper degrees of non-membership and $\pi^{U}{}_{\tilde{A}s}(x)$ is the hesitancy of x to $\tilde{A}s$. An IVSFS is defined as;

$$\langle [\mu^{L}{}_{\tilde{A}s}(x), \mu^{U}{}_{\tilde{A}s}(x)], [v^{L}{}_{\tilde{A}s}(x), v^{U}{}_{\tilde{A}s}(x)], [\pi^{L}{}_{\tilde{A}s}(x), \pi^{U}{}_{\tilde{A}s}(x)]$$

is indicated by

$\tilde{\alpha} = \langle [a_s, b_s], [c_s, d_s], [e_s, f_s] \rangle$ where;

$[a_s, b_s] \subset [0,1]$, $[c_s, d_s] \subset [0,1]$, $[e_s, f_s] \subset [0,1]$

and $b_s{}^2 + d_s{}^2 + f_s{}^2 \leq 1$.

5.4 Conventional Analytic Hierarchy Process (AHP)

Thomas L.Saaty proposed the Analytic Hierarchy Process (AHP) in 1980 in order to be a decision making method to solve complicated decision-making problems which have various attributes (Saaty, 1980). The steps of AHP are as following:

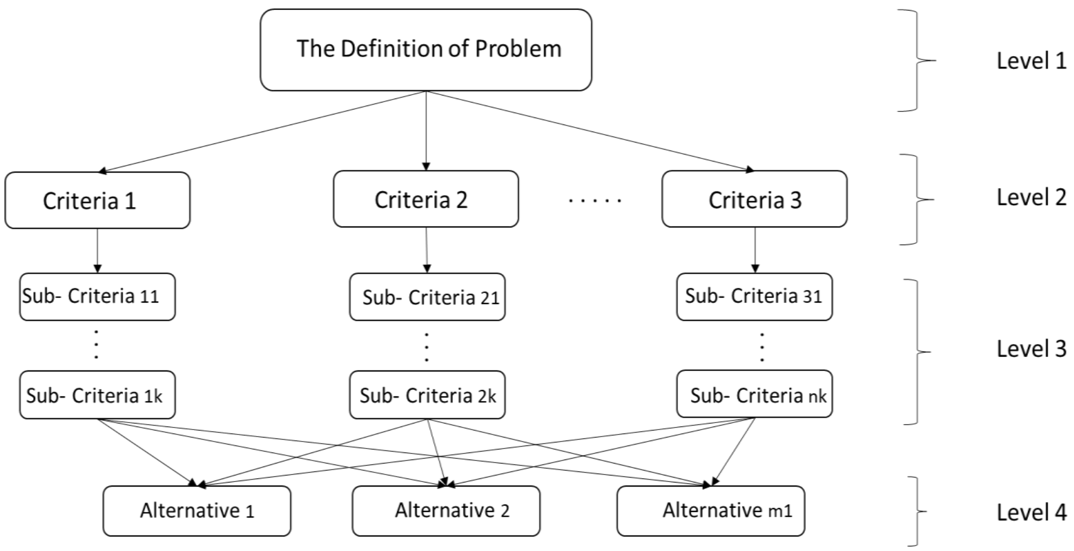


Figure 5.4. Hierarchy structure of AHP

Step 1: The structural hierarchy is constructed as shown in the figure 5.4. Firstly, the problem is defined. Secondly, the main criteria are selected. Then, the sub-criteria are specified for each main criterion. In the final level of the hierarchy, the alternatives are specified.

Step 2: The matrix for pairwise comparisons is set. Assuming that there are k attributes. The comparison of feature i with feature j creates a square matrix A_{kxk} where a_{ij} indicates the comparative significance of feature i with respect to feature j.

a_{ij} =1 where i=j.

$$\boldsymbol{A_{kxk}} = \begin{array}{c} \text{Feature} \\ 1 \\ 2 \\ \dots \\ \dots \\ k \end{array} \begin{bmatrix} a_{11} & a_{12} & \dots & \dots & a_{1k} \\ a_{21} & a_{22} & \dots & \dots & a_{2k} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ a_{k1} & a_{k2} & \dots & \dots & a_{kk} \end{bmatrix}$$

Step 3: The decision matrix is normalized.

$$c_{ij} = {a_{ij}}\Big/{\sum_{j=1}^{k} a_{ij}} \qquad \text{i= 1, 2, 3, ..., k} \qquad \text{j=1, 2, 3..., k} \qquad (8)$$

Step 4: The weighted normalized decision matrix is constructed.

$$w_i = \frac{\sum_{j=1}^{k} c_{ij}}{k} \qquad \text{i= 1, 2, 3, ..., k} \qquad \text{j=1, 2, 3..., k} \qquad (9)$$

Step 5: The λ_{max} is calculated.

$$\lambda_{max} = \sum_{j=1}^{k}\left(\left(\sum_{j=1}^{k} a_{ij}\right) * w_{1j}\right) \qquad (10)$$

Step 6: Consistency index and consistency ratio are estimated.

$$CI = \frac{(\lambda_{max} - k)}{(k-1)} \quad (11)$$

$$CR = CI / RI \quad (12)$$

Step 7: After the weights of main criterion and local weights of sub-criteria are obtained, the global weights of the criteria are calculated by multiplication of local weight of each sub-criterion by its corresponding main criterion weight.

5.5 Interval-Valued Spherical Fuzzy AHP (IVSFAHP)

The steps of IVSFAHP are as followings;

Step 1. The first step starts with forming the conventional AHP hierarchy structure which is a 4-level structure. The initial level involves outlining the problem. Subsequently, the second and third levels involve categorizing main criteria and sub-criteria, respectively. The final stage is selection of alternatives. (Figure 5.5).

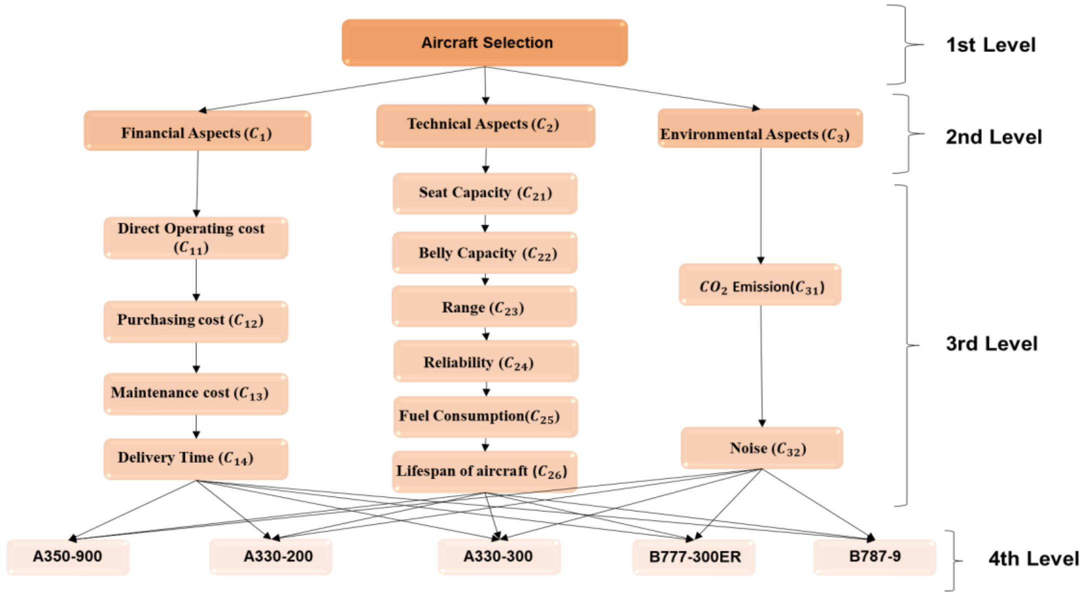


Figure 5.5. Hierarchical structure of aircraft selection problem

Step 2. A measurement reference based on the linguistic preferences of DMs is developed as displayed in Table 5.1. This measurement reference can be used to construct pairwise comparisons by DMs.

Table 5.1 SFSs linguistic expressions

Linguistic expression $\widetilde{\alpha} = \langle [\boldsymbol{a_s}, \boldsymbol{b_s}], [\boldsymbol{c_s}, \boldsymbol{d_s}], [\boldsymbol{e_s}, \boldsymbol{f_s}] \rangle$	**Score Index**
Excessively High Significance (EHS) ([0,850;0,950] | [0,100;0,150] | [0,050;0,150])	9
Quite High Significance (QHS) ([0,750;0,850] | [0,150;0,200] | [0,150;0,200])	7
High Significance (HS) ([0,650;0,750] | [0,200;0,250] | [0,200;0,250])	5
Lightly High Significance (LHS) ([0,550;0,650] | [0,250;0,300] | [0,250;0,300])	3
Equal Significance (ES) ([0,500;0,550] | [0,450;0,550] | [0,300;0,400])	1
Lightly Minor Significance (LMS) ([0,250;0,300] | [0,550;0,650] | [0,250;0,300])	3^{-1}
Minor Significance (MS) ([0,200;0,250] | [0,650;0,750] | [0,200;0,250])	5^{-1}
Quite Minor Significance (QMS) ([0,150;0,200] | [0,750;0,850] | [0,150;0,200])	7^{-1}
Excessively Minor Significance (EMS) ([0,100;0,150] | [0,850;0,950] | [0,050;0,150])	9^{-1}

Step 3. The consistency ratio for each pairwise comparison matrix should be calculated by the Eq. (12). The calculated CR needs to be checked by following the steps of conventional AHP and it must be provided that CRs are below 10%. If any CR is above 10%, then the linguistic preferences should be revised until the expected CR is reached.

Step 4. The numeric importance of IVSFSs is determined by taking into account the preferences of the DMs. Interval-valued spherical weighted arithmetic mean operator (IVSWAM) formula (Equation 13) is used to calculate the criteria and sub-criteria weights.

$\omega = (\omega_1, \omega_2, \dots \dots .., \omega_n)$ $where$ $\omega_1 \in [0, 1]$ and $\sum_{i=1}^{n} \omega_i = 1$

IVSWAM is expressed as;

$$\text{IVSWAM}_{\omega}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_k) = \omega_1.\tilde{a}_1 \oplus \ \omega_2.\tilde{a}_2 \oplus \ \ldots \oplus \ \omega_k.\tilde{a}_k$$

$$IVSWAM_{\omega} = \left\{ \begin{array}{c} \left[(1-\prod_{j=1}^{k}(1-\alpha_j^2)^{\omega_j})^{1/2}, (1-\prod_{j=1}^{k}(1-b_j^2)^{\omega_j})^{1/2}\right], \left[\prod_{j=1}^{k} c_j^{\omega_j}, \prod_{j=1}^{k} d_j^{\omega_j},\right], \\ \left[\left(\prod_{j=1}^{k}(1-\alpha_j^2)^{\omega_j} - \prod_{j=1}^{k}(1-\alpha_j^2-e_j^2)^{\omega_j}\right)^{1/2}, \left(\prod_{j=1}^{k}(1-b_j^2)^{\omega_j} - \prod_{j=1}^{k}(1-b_j^2-f_j^2)^{\omega_j}\right)^{1/2}\right] \end{array} \right\} \quad (13)$$

Step 5. The global weights are calculated. The preference importance of IVSFSs is aggregated for each level of the hierarchy to acquire the score ranks. At that point, there are two approaches which are using partial IVSFAHP (defined in Equations (14 -17)) and using complete IVSFAHP (defined in Equations. (17-18)). In this study the first approach is used.

The Eq. (14) is used to defuzzify the criteria weightings.

Score $\omega_j^S = \text{S}(\tilde{\omega}_j^S)$

$$\text{S}(\tilde{\omega}_j^S) = [\ (\text{a}_s^2 + \text{b}_s^2 - \text{c}_s^2 - \text{d}_s^2 - \left(\frac{\text{e}_s}{2}\right)^2 - \left(\frac{f_s}{2}\right)^2)/2\ ] + 1 \qquad (14)$$

The following formula is used for normalizing the criteria weights

$$\tilde{\omega}_j^S = \frac{\text{S}(\tilde{\omega}_j^S)}{\sum_{j=1}^{n} \text{S}(\tilde{\omega}_j^S)} \qquad (15)$$

For weighting the decision matrix, the following is utilised;

$$\tilde{a}_{S_{ij}} = \overline{\omega}_j^S.\tilde{a}_{S_i},$$

$$\tilde{\alpha}_{S_{ij}} = \left\{ \begin{array}{c} \left[\left(1-\left(1-\alpha_{S_i}^2\right)^{\varpi_j^S}\right)^{\frac{1}{2}}, \left(1-\left(1-b_{S_i}^2\right)^{\varpi_j^S}\right)^{\frac{1}{2}} \right], \\ \left[c_{S_i}^{\varpi_j^S}, d_{S_i}^{\varpi_j^S} \right], \\ \left[\begin{array}{c} \left(\left(1-\alpha_{S_i}^2\right)^{\varpi_j^S} - \left(1-\alpha_{S_i}^2-e_{S_i}^2\right)^{\varpi_j^S}\right)^{\frac{1}{2}}, \\ \left(\left(1-b_{S_i}^2\right)^{\varpi_j^S} - \left(1-b_{S_i}^2-f_{S_i}^2\right)^{\varpi_j^S}\right)^{\frac{1}{2}} \end{array} \right] \end{array} \right\} \quad (16)$$

$$\tilde{F} = \sum_{j=1}^{n} \tilde{\alpha}_{S_{ij}} = \tilde{\alpha}_{S_{i1}} \oplus \tilde{\alpha}_{S_{i2}} \ldots \oplus \tilde{\alpha}_{S_{in}} \forall i$$

$$i.e. \tilde{\alpha}_{S_{11}} \oplus \tilde{\alpha}_{S_{12}}$$

$$= \left\{ \begin{array}{c} \left[\begin{array}{c} \left(\left(\alpha_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(\alpha_{\tilde{\alpha}_{12}}\right)^2 - \left(\alpha_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(\alpha_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}}, \\ \left(\left(b_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(b_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(b_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(b_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}} \end{array} \right], \left[c_{\tilde{\alpha}_{S_{11}}} c_2, d_{\tilde{\alpha}_{S_{11}}} d_2 \right], \\ \left[\begin{array}{c} \left(\left(1-\left(\alpha_{\tilde{\alpha}_{12}}\right)^2\right)\left(e_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(1-\left(\alpha_{\tilde{\alpha}_{S_{11}}}\right)^2\right)\left(e_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(e_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(e_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}}, \\ \left(\left(1-\left(b_{\tilde{\alpha}_{12}}\right)^2\right)\left(f_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(1-\left(b_{\tilde{\alpha}_{S_{11}}}\right)^2\right)\left(f_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(f_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(f_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}} \end{array} \right] \end{array} \right\} \quad (17)$$

$$\prod_{j=1}^{n} \tilde{\alpha}_{S_{ij}} = \tilde{\alpha}_{S_{i1}} \otimes \tilde{\alpha}_{S_{i2}} \ldots \otimes \tilde{\alpha}_{S_{in}} \forall i$$

$$i.e. \tilde{\alpha}_{S_{11}} \otimes \tilde{\alpha}_{S_{12}}$$

$$= \left\{ \begin{array}{c} \left[\alpha_{\tilde{\alpha}_{S_{11}}} \alpha_2, b_{\tilde{\alpha}_{S_{11}}} b_2 \right], \left[\begin{array}{c} \left(\left(c_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(c_{\tilde{\alpha}_{12}}\right)^2 - \left(c_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(c_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}}, \\ \left(\left(d_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(d_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(d_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(d_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}} \end{array} \right], \\ \left[\begin{array}{c} \left(\left(1-\left(c_{\tilde{\alpha}_{12}}\right)^2\right)\left(e_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(1-\left(c_{\tilde{\alpha}_{S_{11}}}\right)^2\right)\left(e_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(e_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(e_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}}, \\ \left(\left(1-\left(d_{\tilde{\alpha}_{12}}\right)^2\right)\left(f_{\tilde{\alpha}_{S_{11}}}\right)^2 + \left(1-\left(d_{\tilde{\alpha}_{S_{11}}}\right)^2\right)\left(f_{\tilde{\alpha}_{S_{12}}}\right)^2 - \left(f_{\tilde{\alpha}_{S_{11}}}\right)^2 \left(f_{\tilde{\alpha}_{S_{12}}}\right)^2\right)^{\frac{1}{2}} \end{array} \right] \end{array} \right\} \quad (18)$$

Step 6. In this step, the defuzzification of final score of each alternative and normalization of the defuzzified values are calculated.

Step 7. As the final step of the procedure, the ranking of alternatives is determined with respect to the normalized and defuzzified final scores. The highest final score value is defined as the best alternative.

6. NUMERICAL ANALYSIS

After the explanation of theoretical background of IVSF-AHP, the method is exemplified with the numerical application of aircraft selection from a private company. As in the first step of the method, the problem is identified which is the selection of an aircraft. Afterwards, the main criteria and sub-criteria are defined by three DMs. There are three main criteria that are financial aspects, technical attributes and environmental aspects, and twelve sub criteria which are direct operating cost, purchasing cost, maintenance cost, delivery time, seat capacity, belly capacity, range, reliability, fuel consumption, lifespan of aircraft, CO_2 emission and noise (Figure 6.1).

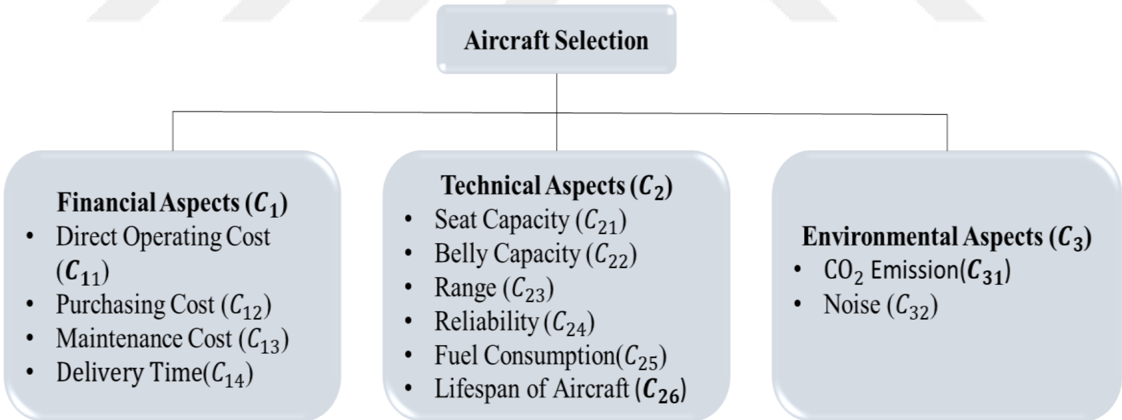


Figure 6.1. Criteria diagram

Criteria mentioned in this study have been utilized in past academic research models. The subsequent table (Table 6.1) outlines the criteria employed in a study conducted by particular academic researchers.

Table 6.1. The list of references for used criteria

#	Criteria	#	Sub-Criteria	Covered by
C_1	Financial Aspects	C_{11}	Direct Operating Cost	Yeh & Chang, 2009; Özdemir et al., 2011; Gomes et al., 2014; Özdemir & Başlıgil, 2016; Akan & Kiracı, 2020; Bakır et al., 2021; Deveci et al., 2022
		C_{12}	Purchasing Cost	Yeh & Chang, 2009; Özdemir et al., 2011; Bruno et al., 2015; Özdemir and Başlıgil, 2016; Bakır & Kiracı, 2018; Dozic et al., 2018; İlgin, 2019; Ardil, 2020; Akyurt & Kabadayı ,2020; Ahmed et al., 2020; Şener & Yılanlı, 2020; Akan & Kiracı, 2020; Bakır et al., 2021; Kartal, 2022
		C_{13}	Maintenance Cost	Özdemir et al., 2011; Özdemir & Başlıgil, 2016; Dozic et al., 2018; Şener & Yılanlı, 2020; Akyurt & Kabadayı, 2020; Akan & Kiracı, 2020; Bakır et al., 2021
		C_{14}	Delivery Time	Özdemir et al., 2011; Özdemir & Başlıgil, 2016; Dozic et al., 2018; Akyurt & Kabadayı, 2020; Şener & Yılanlı, 2020;
C_2	Technical Aspects	C_{21}	Seat Capacity	Sun et al., 2011; Dozic et al., 2018; Bakır & Kiracı, 2018; İlgin, 2019; Ardil, 2020; Akan & Kiracı, 2020; Ahmed et al., 2020; Şener & Yılanlı, 2020; Bakır et al., 2021; Deveci et al., 2022; Kartal, 2022
		C_{22}	Belly Capacity	Akyurt & Kabadayı ,2020; Ahmed et al., 2020; Şener & Yılanlı, 2020; Kartal, 2022
		C_{23}	Range	Yeh & Chang, 2009; Gomes et al., 2014; Bakır & Kiracı, 2018; Dozic et al., 2018; İlgin, 2019; Ardil, 2020; Akyurt & Kabadayı ,2020; Ahmed et al., 2020; Şener & Yılanlı, 2020; Akan & Kiracı, 2020; Bakır et al., 2021; Kartal, 2022
		C_{24}	Reliability	Yeh & Chang, 2009; Özdemir et al., 2011; Özdemir & Başlıgil, 2016
		C_{25}	Fuel Consumption	Sun et al., 2011; Bakır & Kiracı, 2018 İlgin, 2019; Ardil, 2020; Akan and Kiracı, 2020
		C_{26}	Lifespan of Aircraft	Özdemir & Başlıgil, 2016; Akyurt & Kabadayı, 2020; Bakır et al., 2021
C_3	Environmental Aspects	C_{31}	CO2 Emission	Akan & Kiracı, 2020; Bakır et al., 2021
		C_{32}	Noise	Yeh & Chang, 2009; Bruno et al. ,2015; Akyurt & Kabadayı ,2020; Akan & Kiracı, 2020; Şener and Yılanlı, 2020; Bakır et al., 2021

6.1 The Definition of Criteria

The brief summaries of criteria are as follows.

Financial Aspects (C_1):

Financial aspects are critical factors that should be taken into consideration before purchasing an aircraft since it is an essential investment for airline companies. There are several financial criteria for an airline such as direct operating cost, purchasing expense, maintenance cost and delivery time. There is also indirect operating cost but it is ignored in this study owing to the fact that it depends on airline's operations and every airline has different operations. The costs which are considered in this study are related to aircraft type.

Direct Operating Cost (C_{11}):

This criterion is the cost of running the aircraft. Direct operating cost includes fuel expense, ownership cost, handling expenses, and crew fees. Fuel cost is based on the fuel price and fuel consumption of the aircraft (Camilleri, 2018). Ownership cost includes depreciation and insurance cost of the aircraft. Handling cost is applied by ground handling agencies and airport authorities in order to provide services like check-in, boarding, baggage/ cargo loading, cleaning of aircraft and so on (Camilleri,2018). Handling cost varies on aircraft type. It increases when the unit volume of aircraft is high. Crew fee is the total cost of cockpit and cabin crew which differs from one airline company to another (in million $).

Purchasing Cost (C_{12}):

The aircraft's market price assigned by the manufacturer. In general, manufacturers apply discounts as airlines request. However, in this study, the price is the list price of aircrafts and the fact of discount is ignored (in million $).

Maintenance Cost (C_{13}):

Aircraft maintenance includes repair, overhaul on engines and components, modification, inspection, and condition determination. Aircraft maintenance ensures a fully serviceable aircraft at minimum cost when it is required by an airline. Aircraft maintenance is inevitable in the airline industry in order to meet safety necessities. Also, punctuality performance is very crucial for airlines. It is required to execute the maintenance in time to avoid delay in a flight schedule. Therefore, it is necessary to make a heavy investment in spare parts to have an efficient punctuality performance (Camilleri, 2018) (in million $).

Delivery Time ($\boldsymbol{C_{14}}$):

The time that the aircraft can be delivered by the manufacturer. Each aircraft type has different delivery time. Airline firms want to receive the aircraft as soon as possible to operate the flight in order to get more profit (the unit is the number of years).

Technical Aspects ($\boldsymbol{C_2}$):

Technical aspects are the operational capability of an aircraft including seat capacity, belly capacity, range, reliability, fuel consumption and the life of aircraft. Taking these technical aspects into consideration provides that the chosen aircraft compatible with the operational goals, safety standards, and financial matter of the operator. It also helps to maximize the overall effectiveness and efficiency of the aircraft.

Technical aspects are essential in order to make long term plans and strategic decisions. Airlines can decide the frequency and the route (direct or with stops) for the destination points based on technical aspects of aircrafts.

Seat Capacity ($\boldsymbol{C_{21}}$):

This is the number of seats in the aircraft. Aircraft cabin is classified as narrow-body which is using for short to medium haul and has only one aisle providing the total passenger capacity up to 250 and wide-body, suitable for long-haul flights, in which there are two aisles providing the total passenger capacity of 200 to 850 in fuselage. This criterion is one of the crucial factors that affects airlines' profitability.

According to Airbus (2022(a)), the passenger traffic will increase by 3.6% in 20 years. Therefore, DMs need to select the aircraft with the right number of seats to match demand with supply.

Belly Capacity ($\boldsymbol{C_{22}}$):

The capacity reserved for luggage and freight in a passenger aircraft. Air cargo transportation has a growing trend and is a critical parameter for revenue. Although airlines have cargo aircrafts, belly of aircrafts are also used to carry cargoes (The unit is kg).

Even though Covid-19 seriously damaged the airline industry, air cargo played an important role to transport goods especially pharmaceutical products during pandemic. Boeing (2022) estimates that the air cargo will grow annually by 4.1% in the next 20 years. As a result, belly capacity should be considered for choosing an aircraft.

Range ($\boldsymbol{C_{23}}$):

Range is the maximum distance that an aircraft can fly from the departure point to the arrival point, (The unit is km). The larger the aircraft gets, the higher the range becomes. The range of an aircraft may vary depending on the number of passengers, cargo load and fuel amount carried by the aircraft. Range is also critical factor for airlines if they want to fly to a new destination.

Reliability ($\boldsymbol{C_{24}}$):

Reliability is the property of a component, item, system or aircraft stated by the probability of the fact that it will perform a necessary function in a given environment for a certain period. The reliability of engines and systems of an aircraft is important to actualize operations safely during the flight. New aircrafts have priority of being chosen due to the fact that they have higher reliability as the developments in technology increases the performance of aircraft equipment.

Fuel Consumption ($\boldsymbol{C_{25}}$):

It is the measure of the aircraft's burned fuel during the flight, (kg/hr). Aircraft manufacturers are designing aircraft with advanced aerodynamics and fuel-efficient engines in order to diminish fuel consumption per passenger and ton of freight. Therefore, fuel consumption is a crucial issue for selecting an aircraft in order to decrease both environmental impact and cost. Hence, aircrafts with low fuel consumption are more preferable for airlines.

The Life of Aircraft ($\boldsymbol{C}_{26}$):

The number of years that an aircraft can be operated before its retirement. Each aircraft type has different lifecycle based on the usage and the technology they are built on.

Environmental Aspects ($\boldsymbol{C_3}$):

$\mathrm{CO_2}$ emission and noise level are the two fundamental environmental factors that are considered in aviation industry. With serious impacts they have, both airlines and aircraft manufacturers try to diminish the level of each factor to protect environment.

$\mathrm{CO_2}$ Emission ($\boldsymbol{C_{31}}$):

CO_2 emission of aircraft refers to the release of CO_2 into the atmosphere due to aviation fuel burn during a flight. The carbon emission is a serious issue that is considered by airlines and it is tried to be reduced to decrease the level of damage that is caused by fuel of the aircrafts. CO2 is the most common gas released into the atmosphere. The aviation sector generates 2.1% of total emissions of CO2 (ATAG, 2020).

Sustainable Aviation Fuel (SAF) is a non-conventional aviation fuel that is employed to power the aircraft with lower carbon footprint (IATA, n.d.). The international aviation industry has a goal to reach net zero carbon by 2050. Therefore, the airlines prioritize SAF and strive to decrease the CO2 emissions in order to achieve this target by investing on their fleet. (The unit is kg/100 km per pax as kg per 100 passenger km).

Noise ($\boldsymbol{C_{32}}$):

Since the population has grown in the cities and the residential areas have spread across the airports, the number of people affecting by aircraft noise has increased in recent years (Ganic et al., 2015). The noise obtained by aircrafts has damage on both human and animals. There are two main reasons why aircrafts produce noise: aeronautical noise which is the result of the friction of air throughout the aircraft and the noise of engine (Prats et al., 2009).

Some airport authorities in some countries have sound limit for aircraft's landing and taking off operations (Yeh & Chang, 2009). Therefore, the noise level of aircraft is important in order to be able to use it in certain countries, (the unit is in decibels).

We selected five different alternatives which are A350-900, A330-200, A330-300, B777-300ER and B787-9. These alternatives are all wide-body. The features of the aircrafts are given in Table 6.2.

Table 6.2. Aircrafts' features

	A350-900	**A330-200**	**A330-300**	**B777-300ER**	**B787-9**
Maximum Range	15,372 km	13,450 km	11,750 km	13,649 km	14,010 km
Seat Capacity	350	250	290	396	296
Belly Capacity	17 tons	14 tons	16 tons	25.2 tons	11 tons
Fuel Consumption	5800 kg/hr	5590 kg/hr	5700 kg/hr	7500 kg/hr	5600 kg/hr
Price	$317.4M	$231.5M	$256.4M	$375.5M	$292.5M

6.2 Aircraft Manufacturers: Boeing and Airbus

Boeing

Boeing was established in 1916 by William Boeing in America. The company produces and develops commercial aircrafts, defense products and space systems. Boeing manufactures different types of aircraft families such as 737, 747, 767, 777 and 787 which includes narrow body, wide body and freighters. Boeing is known for its commitment to technological developments and safety in aviation (Boeing, n.d.).

Airbus

Airbus was founded in 1970 and is a leading company which designs, produces and delivers aerospace products, services and solutions (Airbus, 2023). Airbus is recognized for its innovative aircraft designs. The company provides various commercial aircraft families such as A220, A320, A330, A350, and A380.

6.3 Aircrafts Features

Airbus A350-900:

A350-900 is the first model of A350 family and it is a medium and long-range wide-body passenger aircraft which is designed by Airbus to compete with the B787. With its CFRP (carbon fiber reinforced plastic) structure, it is much lighter and aerodynamic. Since it has new generation Rolls-Royse Trent XWB engines, this aircraft is designed to be quieter, 25% less fuel burn and CO2 emissions. The noise footprint of A350-900 has been reduced by 50%.

A350-900, as the cornerstone member in Airbus' A350 family, is designed to accommodate 300-350 passenger seats in a typical three-class configuration. It operates efficiently across various distances from short-range to ultra-long-range routes that extend up to 18,000 kilometers. (Airbus, 2022(b)).

Table 6.3. A350-900's Features

Feature	Measure
Overall length	66.8m
Height	17.05 m
Wing span	64.75 m
Maximum take-off weight (MTOW)	283 tonnes
Engine	Rolls-Royce Trent XWB

Figure 6.2. Airbus A350-900 (Airbus, 2024(a))

Airbus A330-300:

A330-300 is a wide-body aircraft with twin engines. It has a "fly-by-wire" digital control system. A330-300 can carry more weight and is much more environmentally friendly than previous models with its reduced overall weight and advanced engines. It is equipped with green technologies, ensures fuel efficiency with its advanced engines and flies with low CO_2 emissions. The maximum takeoff weight capability increased to 242 metric tonnes. With this improvement, A330-300 can connect city pairs such as London-Tokyo and Los Angeles to Dublin.

A330-300 accommodates between 250-440 passenger seats in a two-class configuration. As it is known with its versatility, the A330-300 can be operated for both medium and long-haul flights with a range of 11,750 kilometer (Airbus n.d (a)).

Table 6.4. A330-300's Features

Feature	Measure
Entire length	62.96 meter
Altitude	17.1 meter
Wing-span	59.9 meter
Maximum take-off weight (MTOW)	242 tonnes
Engine	GE CF6-80E / PW4000 / Rolls-Royce Trent

Figure 6.3. Airbus A330-300 (Airbus, 2024(b))

Airbus A330-200:

The A330-200 is a WB and twin-engine commercial aircraft. It made its first flight in 1997. The body of the A330-200 is approximately 4.7 meters shorter than the A330-300, but its range is 2 thousand kilometers longer than the A330-300 which is 13,450 km. This range difference was a result of a special fuel tank placed under the fuselage of the A330-200. Special landing gear has been added in order to accommodate the increased weight (Airbus, n.d.(b)).

The A330-200 can carry from 210 to 250 passengers in its twin- aisle fuselage. It offers the option to arrange seating in higher-density layouts, accommodating as many as 406 seats.

Table 6.5. A330-200's Features

Feature	**Measure**
Entire length	59.1 meter
Altitude	17.2 meter
Wing-span	59.9 meter
Maximum take-off weight (MTOW)	251 tonnes
Engine	GE CF6-80E / PW4000 / Rolls-Royce Trent 7

Figure 6.4. Airbus A330-200 (Airbus, 2024(c))

Boeing B777-300ER:

The Boeing 777-300ER has two GE90-115B jet engines with 175,000 horsepower and can accelerate from 0 to 96 km in 6 seconds. The aircraft can reach higher speeds, rise faster and fly at higher altitudes with its 64.8 m wide wingspan compared to similar models. The aerodynamic performance is increased by adding 1.9 m long curved tips to the wings.

B777-300ER accommodates approximately 365 passengers in a three-class configuration. It is known with its impressive range, capable of flying over 13,649 km. This extended range allows it to operate in long-haul flights. Since B777-300ER offers a combination of range, capacity, and fuel efficiency, it has been popular choice among airlines for long-haul operations (Boeing, 2023 (a).

Table 6.6. Boeing B777-300ER’s Features

Feature	Measure
Entire length	74.1 meter
Altitude	19.2 meter
Wing-span	64.8 meter
Maximum take-off weight (MTOW)	351 tonnes
Engine	GE90-115BL

Figure 6.5. Boeing B777-300ER (ORIX Aviation, 2024)

Boeing B787-9:

B787-9 which is also known as Dreamliner is a long-range WB aircraft with twin engine. It is designed with a high proportion of composite which results in a high humidity indoor environment. Being the first aircraft to be made of composite material, the 787-9 will save 10% in operating costs and 20% in fuel costs. The noise area will be reduced by 60% in the new aircraft, which will also reduce CO2 emissions by 20%.

B787-9 can carry around 290 passengers in a two-class configuration and up to 296 passengers in three-class configuration. It is capable of flying over 14,010 kilometers with a full passenger load which makes it suitable for long-haul flights (Boeing, 2023(b)).

Table 6.7. Boeing B787-9's Features

Feature	**Measure**
Entire length	63 meter
Altitude	17 meter
Wing-span	60 meter
Maximum take-off weight (MTOW)	254 tonnes
Engine	GEnx-1B / Trent 1000

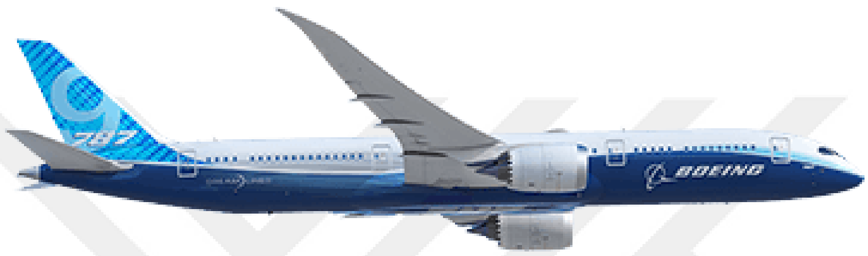


Figure 6.6. Boeing B787-9 (Boeing, 2024)

7. RESULTS

After establishing the criteria and sub-criteria, three decision-makers with experience in aircraft procurement process management in the private airline industry carefully examined each one of them. Using relevant linguistic indices shown in Table 5.1. as a starting point, we constructed the consistency ratio (CR) values for the pairwise comparison matrix of the IVSFS. The pairwise comparison and IVSFSs weights are shown in Tables 7.1-7.17. Tables are also used to display the CR values. The final rating results for comparable competing alternative aircrafts are shown in Table 7.18.

DMs are asked to evaluate the pairwise comparison of three main criteria. According to their judgments, each criterion's IVSAM and weights are found by equation 13, 14 and 15 respectively. Afterwards, CRs are found by Equation 12. Table 7.1. shows the DMs' overall pairwise comparison of each main criterion.

$$CR = CI\,/\,RI \qquad (12)$$

$$IVSWAM_{\omega} = \left\{ \begin{array}{c} \left[(1-\prod_{j=1}^{k}(1-\alpha_j^2)^{\omega_j})^{1/2}, (1-\prod_{j=1}^{k}(1-b_j^2)^{\omega_j})^{1/2}\right], \left[\prod_{j=1}^{k} c_j^{\omega_j}, \prod_{j=1}^{k} d_j^{\omega_j},\right], \\ \left[\left(\prod_{j=1}^{k}(1-\alpha_j^2)^{\omega_j}-\prod_{j=1}^{k}(1-\alpha_j^2-e_j^2)^{\omega_j}\right)^{1/2}, \left(\prod_{j=1}^{k}(1-b_j^2)^{\omega_j}-\prod_{j=1}^{k}(1-b_j^2-f_j^2)^{\omega_j}\right)^{1/2}\right] \end{array} \right\} \quad (13)$$

$$S(\widetilde{\omega}_j^S) = \left[\ (a_s^2 + b_s^2 - c_s^2 - d_s^2 - \left(\frac{e_s}{2}\right)^2 - \left(\frac{f_s}{2}\right)^2)/2\ \right] + 1 \qquad (14)$$

$$\overline{\omega}_j^S = \frac{S(\widetilde{\omega}_j^S)}{\sum_{j=1}^{n} S(\widetilde{\omega}_j^S)} \qquad (15)$$

Table 7.1. Overall pairwise comparison

		F	T	E	w_S	w_S	CR
DM 1	F	ES	LMS	HS	([0,909;0,887]|[0,766;0,819]|[0,871;0,813])	0,344	
	T	LHS	ES	EHS	([0,887;0,833]|[0,630;0,669]|[0,860;0,787])	0,459	0,039
	E	MS	EMS	ES	([0,986;0,979]|[0,866;0,909]|[0,973;0,956])	0,197	
DM 2	F	ES	LHS	HS	([0,909;0,887]|[0,766;0,819]|[0,871;0,813])	0,413	
	T	LMS	ES	LHS	([0,979;0,969]|[0,819;0,866]|[0,956;0,936])	0,338	0,048
	E	MS	LMS	ES	([0,986;0,979]|[0,866;0,909]|[0,973;0,956])	0,249	
DM 3	F	ES	LMS	HS	([0,909;0,887]|[0,766;0,819]|[0,871;0,813])	0,355	
	T	LHS	ES	QHS	([0,887;0,833]|[0,630;0,669]|[0,860;0,787])	0,430	0,083
	E	MS	QMS	ES	([0,986;0,979]|[0,866;0,909]|[0,973;0,956])	0,215	

DM's are asked to evaluate the pairwise comparison for each main criteria which are displayed from Table 7.2 to Table 7.4.

Table 7.2. Pairwise comparison of the main criteria: Financial Aspects

		C_{F1}	C_{F2}	C_{F3}	C_{F4}	w_s	w_s	CR
DM 1	C_{F1}	ES	EHS	QHS	EHS	([0,775;0,890]|[0,161;0,223]|[0,139;0,208])	0,386	
	C_{F2}	EMS	ES	LMS	ES	([0,387;0,435]|[0,555;0,657]|[0,258;0,348])	0,181	0,077
	C_{F3}	QMS	LHS	ES	LHS	([0,477;0,559]|[0,381;0,453]|[0,251;0,319])	0,251	
	C_{F4}	EMS	ES	LMS	ES	([0,387;0,435]|[0,555;0,657]|[0,258;0,348])	0,181	
DM 2	C_{F1}	ES	QHS	LHS	EHS	([0,706;0,823]|[0,203;0,265]|[0,185;0,248])	0,354	
	C_{F2}	QMS	ES	LMS	LHS	([0,410;0,479]|[0,464;0,549]|[0,251;0,322])	0,214	
	C_{F3}	LMS	LHS	ES	QHS	([0,565;0,660]|[0,310;0,383]|[0,237;0,299])	0,288	0,059
	C_{F4}	EMS	LMS	QMS	ES	([0,303;0,349]|[0,630;0,733]|[0,222;0,299])	0,145	
DM 3	C_{F1}	ES	QHS	ES	EHS	([0,699;0,813]|[0,235;0,309]|[0,198;0,266])	0,335	
	C_{F2}	QMS	ES	QMS	LHS	([0,399;0,468]|[0,502;0,588]|[0,234;0,307])	0,197	
	C_{F3}	ES	QHS	ES	EHS	([0,699;0,813]|[0,235;0,309]|[0,198;0,266])	0,335	0,054
	C_{F4}	EMS	LMS	EMS	ES	([0,298;0,343]|[0,650;0,754]|[0,212;0,294])	0,133	

Table 7.3. Pairwise comparison of the main criteria: Technical Aspects

		C_{T1}	C_{T2}	C_{T3}	C_{T4}	C_{T5}	C_{T6}	w_s	w_s	CR
DM 1	C_{T1}	ES	HS	EHS	LMS	QHS	QHS	([0,687;0,802]|[0,219;0,285]|[0,181;0,244])	0,230	0,10
	C_{T2}	MS	ES	HS	MS	LHS	LHS	([0,489;0,576]|[0,365;0,437]|[0,240;0,304])	0,171	
	C_{T3}	EMS	MS	ES	EMS	LMS	LMS	([0,277;0,322]|[0,632;0,735]|[0,217;0,288])	0,094	
	C_{T4}	LHS	HS	EHS	ES	QHS	QHS	([0,706;0,818]|[0,192;0,251]|[0,182;0,241])	0,236	
	C_{T5}	QMS	LMS	LHS	QMS	ES	ES	([0,400;0,463]|[0,500;0,591]|[0,250;0,327])	0,134	
	C_{T6}	QMS	LMS	LHS	QMS	ES	ES	([0,400;0,463]|[0,500;0,591]|[0,250;0,327])	0,134	
DM 2	C_{T1}	ES	HS	QHS	LMS	HS	QHS	([0,635;0,736]|[0,246;0,310]|[0,207;0,264])	0,219	0,077
	C_{T2}	MS	ES	LHS	QMS	LHS	LHS	([0,461;0,545]|[0,388;0,460]|[0,245;0,310])	0,168	
	C_{T3}	QMS	LMS	ES	EMS	LMS	LHS	([0,355;0,420]|[0,528;0,619]|[0,233;0,302])	0,128	
	C_{T4}	LHS	QHS	EHS	ES	HS	EHS	([0,731;0,850]|[0,180;0,239]|[0,166;0,230])	0,250	
	C_{T5}	MS	LMS	MS	MS	ES	LHS	([0,360;0,425]|[0,507;0,597]|[0,242;0,309])	0,132	
	C_{T6}	QMS	LMS	LMS	EMS	LMS	ES	([0,287;0,333]|[0,602;0,704]|[0,231;0,300])	0,103	
DM 3	C_{T1}	ES	HS	ES	QMS	ES	HS	([0,531;0,609]|[0,374;0,455]|[0,251;0,329])	0,177	0,098
	C_{T2}	MS	ES	MS	EMS	MS	ES	([0,334;0,380]|[0,601;0,704]|[0,235;0,317])	0,106	
	C_{T3}	ES	HS	ES	QMS	ES	HS	([0,531;0,609]|[0,374;0,455]|[0,251;0,329])	0,177	
	C_{T4}	QHS	EHS	QHS	ES	QHS	EHS	([0,767;0,878]|[0,157;0,215]|[0,143;0,207])	0,256	
	C_{T5}	ES	HS	ES	QMS	ES	HS	([0,531;0,609]|[0,374;0,455]|[0,251;0,329])	0,177	
	C_{T6}	MS	ES	MS	EMS	MS	ES	([0,334;0,380]|[0,601;0,704]|[0,235;0,317])	0,106	

Table 7.4. Pairwise comparison of the main criteria: Environmental Aspects

		C_{E1}	C_{E2}	w_s	w_s	CR
DM 1	C_{E1}	ES	ES	([0,500;0,550]|[0,450;0,550]|[0,300;0,400])	0,500	N/A
	C_{E2}	ES	ES	([0,500;0,550]|[0,450;0,550]|[0,300;0,400])	0,500	
DM 2	C_{E1}	ES	EHS	([0,737;0,860]|[0,212;0,287]|[0,174;0,245])	0,696	N/A
	C_{E2}	EMS	ES	([0,372;0,417]|[0,618;0,723]|[0,233;0,331])	0,304	
DM 3	C_{E1}	ES	QHS	([0,654;0,748]|[0,260;0,332]|[0,222;0,288])	0,653	N/A
	C_{E2}	QMS	ES	([0,379;0,426]|[0,581;0,684]|[0,250;0,339])	0,347	

After evaluating the overall comparison and each main criterion, the pairwise comparison of each aircrafts under each sub-criteria is generated as it is shown by Table 7.5 - 16.

Table 7.5. Pairwise comparison of aircrafts for the criterion: C_{F1}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	HS	HS	ES	ES	([0,570;0,649]|[0,325;0,401]|[0,260;0,337])	0,236	0,000
	AC_2	MS	ES	ES	MS	MS	([0,361;0,409]|[0,561;0,662]|[0,253;0,336])	0,146	
	AC_3	MS	ES	ES	MS	MS	([0,361;0,409]|[0,561;0,662]|[0,253;0,336])	0,146	
	AC_4	ES	HS	HS	ES	ES	([0,570;0,649]|[0,325;0,401]|[0,260;0,337])	0,236	
	AC_5	ES	HS	HS	ES	ES	([0,570;0,649]|[0,325;0,401]|[0,260;0,337])	0,236	
DM 2	AC_1	ES	QHS	QHS	HS	LHS	([0,659;0,759]|[0,219;0,278]|[0,208;0,263])	0,275	0,051
	AC_2	QMS	ES	ES	LMS	MS	([0,362;0,410]|[0,558;0,660]|[0,255;0,338])	0,145	
	AC_3	QMS	ES	ES	LMS	MS	([0,362;0,410]|[0,558;0,660]|[0,255;0,338])	0,145	
	AC_4	MS	LHS	LHS	ES	LMS	([0,447;0,526]|[0,399;0,475]|[0,256;0,322])	0,198	
	AC_5	LMS	HS	HS	LHS	ES	([0,551;0,642]|[0,301;0,367]|[0,241;0,302])	0,236	
DM 3	AC_1	ES	QHS	QHS	HS	ES	([0,653;0,749]|[0,247;0,313]|[0,218;0,281])	0,268	0,006
	AC_2	QMS	ES	ES	ES	QMS	([0,408;0,455]|[0,552;0,655]|[0,262;0,355])	0,152	
	AC_3	QMS	ES	ES	ES	QMS	([0,408;0,455]|[0,552;0,655]|[0,262;0,355])	0,152	
	AC_4	MS	ES	ES	ES	MS	([0,415;0,464]|[0,521;0,623]|[0,272;0,363])	0,160	
	AC_5	ES	QHS	QHS	HS	ES	([0,653;0,749]|[0,247;0,313]|[0,218;0,281])	0,268	

Table 7.6. Pairwise comparison of aircrafts for the criterion: C_{F2}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	MS	LMS	LHS	QMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,162	0,046
	AC_2	HS	ES	ES	HS	LMS	([0,542;0,624]|[0,339;0,415]|[0,251;0,322])	0,223	
	AC_3	LHS	ES	ES	HS	LMS	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,215	
	AC_4	LMS	MS	MS	ES	EMS	([0,291;0,338]|[0,616;0,718]|[0,225;0,297])	0,120	
	AC_5	QHS	LHS	LHS	EHS	ES	([0,681;0,798]|[0,211;0,272]|[0,197;0,258])	0,280	
DM 2	AC_1	ES	QMS	MS	LHS	LMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,158	0,070
	AC_2	QHS	ES	ES	EHS	HS	([0,690;0,802]|[0,227;0,296]|[0,198;0,265])	0,272	
	AC_3	HS	ES	ES	EHS	LHS	([0,652;0,766]|[0,252;0,321]|[0,218;0,286])	0,259	
	AC_4	LMS	EMS	EMS	ES	QMS	([0,276;0,320]|[0,669;0,772]|[0,202;0,279])	0,102	
	AC_5	LHS	MS	LMS	QHS	ES	([0,521;0,612]|[0,360;0,438]|[0,233;0,297])	0,210	
DM 3	AC_1	ES	QMS	MS	LHS	LMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	0,083
	AC_2	QHS	ES	LHS	EHS	HS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,282	
	AC_3	HS	LMS	ES	QHS	LHS	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,241	
	AC_4	LMS	EMS	QMS	ES	MS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_5	LHS	MS	LMS	HS	ES	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,202	

Table 7.7. Pairwise comparison of aircrafts for the criterion: C_{F3}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM1	AC_1	ES	LHS	HS	LHS	QHS	([0,616;0,714]|[0,243;0,301]|[0,229;0,285])	0,262	0,039
	AC_2	LMS	ES	LHS	ES	HS	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,219	
	AC_3	MS	LMS	ES	LMS	LHS	([0,388;0,455]|[0,467;0,554]|[0,256;0,323])	0,173	
	AC_4	LMS	ES	LHS	ES	HS	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,219	
	AC_5	QMS	MS	LMS	MS	ES	([0,295;0,343]|[0,601;0,702]|[0,232;0,302])	0,127	
DM2	AC_1	ES	EMS	MS	LMS	MS	([0,291;0,338]|[0,616;0,718]|[0,225;0,297])	0,119	0,070
	AC_2	EHS	ES	LHS	EHS	HS	([0,727;0,849]|[0,186;0,247]|[0,169;0,235])	0,293	
	AC_3	HS	LMS	ES	HS	ES	([0,542;0,624]|[0,339;0,415]|[0,251;0,322])	0,220	
	AC_4	LHS	EMS	MS	ES	LMS	([0,376;0,443]|[0,509;0,598]|[0,236;0,308])	0,158	
	AC_5	HS	MS	ES	LHS	ES	([0,513;0,592]|[0,366;0,443]|[0,256;0,329])	0,210	
DM3	AC_1	ES	MS	MS	LHS	LHS	([0,443;0,522]|[0,412;0,489]|[0,249;0,316])	0,193	0,095
	AC_2	HS	ES	ES	HS	HS	([0,599;0,688]|[0,277;0,343]|[0,240;0,307])	0,249	
	AC_3	HS	ES	ES	QHS	HS	([0,627;0,720]|[0,261;0,328]|[0,229;0,293])	0,259	
	AC_4	LMS	MS	QMS	ES	LMS	([0,303;0,350]|[0,581;0,683]|[0,241;0,310])	0,131	
	AC_5	LMS	MS	MS	LHS	ES	([0,383;0,450]|[0,482;0,570]|[0,249;0,317])	0,168	

Table 7.8. Pairwise comparison of aircrafts for the criterion: C_{F4}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	
DM 1	AC_1	ES	LHS	LHS	QHS	HS	([0,616;0,714]|[0,243;0,301]|[0,229;0,285])	0,263	0,081
	AC_2	LMS	ES	LHS	LHS	LHS	([0,499;0,586]|[0,329;0,395]|[0,262;0,324])	0,222	
	AC_3	LMS	LMS	ES	LHS	LHS	([0,451;0,530]|[0,385;0,461]|[0,263;0,328])	0,202	
	AC_4	QMS	LMS	LMS	ES	LMS	([0,310;0,358]|[0,562;0,663]|[0,250;0,318])	0,139	
	AC_5	MS	LMS	LMS	LHS	ES	([0,388;0,455]|[0,467;0,554]|[0,256;0,323])	0,174	
DM 2	AC_1	ES	MS	MS	LMS	LMS	([0,308;0,356]|[0,565;0,666]|[0,248;0,316])	0,137	0,063
	AC_2	HS	ES	ES	HS	HS	([0,599;0,688]|[0,277;0,343]|[0,240;0,307])	0,251	
	AC_3	HS	ES	ES	HS	HS	([0,599;0,688]|[0,277;0,343]|[0,240;0,307])	0,251	
	AC_4	LHS	MS	MS	ES	ES	([0,429;0,494]|[0,463;0,552]|[0,261;0,340])	0,180	
	AC_5	LHS	MS	MS	ES	ES	([0,429;0,494]|[0,463;0,552]|[0,261;0,340])	0,180	
DM 3	AC_1	ES	LMS	LMS	LHS	LHS	([0,451;0,530]|[0,385;0,461]|[0,263;0,328])	0,202	0,094
	AC_2	LHS	ES	LHS	HS	HS	([0,586;0,681]|[0,257;0,315]|[0,240;0,298])	0,254	
	AC_3	LHS	LMS	ES	LHS	HS	([0,526;0,615]|[0,315;0,381]|[0,251;0,313])	0,231	
	AC_4	LMS	MS	LMS	ES	LHS	([0,388;0,455]|[0,467;0,554]|[0,256;0,323])	0,174	
	AC_5	LMS	MS	MS	LMS	ES	([0,308;0,356]|[0,565;0,666]|[0,248;0,316])	0,138	

Table 7.9. Pairwise comparison of aircrafts for the criterion: C_{T1}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM1	AC_1	ES	HS	QHS	LMS	LHS	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,241	0,083
	AC_2	MS	ES	LHS	QMS	LMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	
	AC_3	QMS	LMS	ES	EMS	MS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_4	LHS	QHS	EHS	ES	HS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,282	
	AC_5	LMS	LHS	HS	MS	ES	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,202	
DM2	AC_1	ES	QHS	ES	MS	LHS	([0,550;0,638]|[0,346;0,423]|[0,244;0,315])	0,220	0,084
	AC_2	QMS	ES	QMS	EMS	LMS	([0,280;0,325]|[0,653;0,755]|[0,210;0,284])	0,107	
	AC_3	ES	QHS	ES	MS	LHS	([0,550;0,638]|[0,346;0,423]|[0,244;0,315])	0,220	
	AC_4	HS	EHS	HS	ES	EHS	([0,739;0,858]|[0,178;0,239]|[0,160;0,227])	0,294	
	AC_5	LMS	LHS	LMS	EMS	ES	([0,382;0,448]|[0,492;0,581]|[0,244;0,315])	0,160	
DM3	AC_1	ES	QHS	LHS	LMS	HS	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,241	0,083
	AC_2	QMS	ES	MS	EMS	LMS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_3	LMS	HS	ES	MS	LHS	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,202	
	AC_4	LHS	EHS	HS	ES	QHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,282	
	AC_5	MS	LHS	LMS	QMS	ES	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	

Table 7.10. Pairwise comparison of aircrafts for the criterion: C_{T2}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM1	AC_1	ES	LHS	ES	LMS	HS	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,214	0,085
	AC_2	LMS	ES	MS	MS	HS	([0,422;0,496]|[0,461;0,550]|[0,237;0,305])	0,177	
	AC_3	ES	HS	ES	LMS	HS	([0,542;0,624]|[0,339;0,415]|[0,251;0,322])	0,223	
	AC_4	LHS	HS	LHS	ES	EHS	([0,658;0,776]|[0,224;0,284]|[0,208;0,270])	0,272	
	AC_5	MS	MS	MS	EMS	ES	([0,284;0,330]|[0,637;0,739]|[0,215;0,289])	0,114	
DM2	AC_1	ES	HS	LHS	LMS	QHS	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,239	0,081
	AC_2	MS	ES	LMS	EMS	LHS	([0,376;0,443]|[0,509;0,598]|[0,236;0,308])	0,157	
	AC_3	LMS	LHS	ES	MS	HS	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,200	
	AC_4	LHS	EHS	HS	ES	EHS	([0,727;0,849]|[0,186;0,247]|[0,169;0,235])	0,292	
	AC_5	QMS	LMS	MS	EMS	ES	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,113	
DM3	AC_1	ES	HS	ES	LMS	QHS	([0,576;0,665]|[0,320;0,397]|[0,240;0,308])	0,232	0,086
	AC_2	MS	ES	LMS	QMS	HS	([0,419;0,492]|[0,475;0,564]|[0,231;0,300])	0,172	
	AC_3	ES	LHS	ES	LMS	HS	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,212	
	AC_4	LHS	QHS	LHS	ES	EHS	([0,681;0,798]|[0,211;0,272]|[0,197;0,258])	0,277	
	AC_5	QMS	MS	MS	EMS	ES	([0,278;0,324]|[0,656;0,758]|[0,207;0,282])	0,107	

Table 7.11. Pairwise comparison of aircrafts for the criterion: C_{T3}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	HS	EHS	QHS	LHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,280	0,099
	AC_2	MS	ES	QHS	LHS	LMS	([0,521;0,612]|[0,360;0,438]|[0,233;0,297])	0,213	
	AC_3	EMS	QMS	ES	LMS	QMS	([0,280;0,325]|[0,653;0,755]|[0,210;0,284])	0,108	
	AC_4	QMS	LMS	LHS	ES	MS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,160	
	AC_5	LMS	LHS	QHS	HS	ES	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,239	
DM 2	AC_1	ES	ES	EHS	QHS	HS	([0,690;0,802]|[0,227;0,296]|[0,198;0,265])	0,276	0,096
	AC_2	ES	ES	QHS	HS	LHS	([0,608;0,701]|[0,273;0,340]|[0,239;0,304])	0,246	
	AC_3	EMS	QMS	ES	MS	LMS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_4	QMS	MS	HS	ES	LMS	([0,419;0,492]|[0,475;0,564]|[0,231;0,300])	0,172	
	AC_5	MS	LMS	LHS	LHS	ES	([0,447;0,526]|[0,399;0,475]|[0,256;0,322])	0,192	
DM 3	AC_1	ES	LHS	EHS	QHS	HS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,282	0,083
	AC_2	LMS	ES	QHS	HS	LHS	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,241	
	AC_3	EMS	QMS	ES	LMS	MS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_4	QMS	MS	LHS	ES	LMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	
	AC_5	MS	LMS	HS	LHS	ES	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,202	

Table 7.12. Pairwise comparison of aircrafts for the criterion: C_{T4}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	EHS	QHS	HS	LHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,277	0,097
	AC_2	EMS	ES	LMS	QMS	EMS	([0,276;0,320]|[0,669;0,772]|[0,202;0,279])	0,102	
	AC_3	QMS	LHS	ES	LMS	MS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,158	
	AC_4	MS	QHS	LHS	ES	LMS	([0,521;0,612]|[0,360;0,438]|[0,233;0,297])	0,211	
	AC_5	LMS	EHS	HS	LHS	ES	([0,631;0,751]|[0,262;0,332]|[0,208;0,275])	0,253	
DM 2	AC_1	ES	EHS	EHS	QHS	HS	([0,755;0,871]|[0,168;0,228]|[0,150;0,218])	0,304	0,087
	AC_2	EMS	ES	ES	LMS	MS	([0,359;0,406]|[0,573;0,675]|[0,249;0,334])	0,138	
	AC_3	EMS	ES	ES	LMS	MS	([0,359;0,406]|[0,573;0,675]|[0,249;0,334])	0,138	
	AC_4	QMS	LHS	LHS	ES	LMS	([0,444;0,522]|[0,410;0,487]|[0,251;0,317])	0,190	
	AC_5	MS	HS	HS	LHS	ES	([0,548;0,639]|[0,311;0,378]|[0,234;0,297])	0,229	
DM 3	AC_1	ES	QHS	QHS	HS	LHS	([0,659;0,759]|[0,219;0,278]|[0,208;0,263])	0,272	0,096
	AC_2	QMS	ES	LMS	MS	QMS	([0,290;0,336]|[0,618;0,720]|[0,226;0,296])	0,120	
	AC_3	QMS	LHS	ES	LMS	LMS	([0,384;0,451]|[0,480;0,568]|[0,251;0,318])	0,167	
	AC_4	MS	HS	LHS	ES	LMS	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,204	
	AC_5	LMS	QHS	LHS	LHS	ES	([0,562;0,658]|[0,297;0,365]|[0,239;0,299])	0,237	

Table 7.13. Pairwise comparison of aircrafts for the criterion: C_{T5}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
	AC_1	ES	EHS	QHS	HS	LHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,277	
	AC_2	EMS	ES	LMS	QMS	EMS	([0,276;0,320]|[0,669;0,772]|[0,202;0,279])	0,102	
DM 1	AC_3	QMS	LHS	ES	LMS	MS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,158	0,097
	AC_4	MS	QHS	LHS	ES	LMS	([0,521;0,612]|[0,360;0,438]|[0,233;0,297])	0,211	
	AC_5	LMS	EHS	HS	LHS	ES	([0,631;0,751]|[0,262;0,332]|[0,208;0,275])	0,253	
	AC_1	ES	EHS	EHS	QHS	HS	([0,755;0,871]|[0,168;0,228]|[0,150;0,218])	0,304	
	AC_2	EMS	ES	ES	LMS	MS	([0,359;0,406]|[0,573;0,675]|[0,249;0,334])	0,138	
DM 2	AC_3	EMS	ES	ES	LMS	MS	([0,359;0,406]|[0,573;0,675]|[0,249;0,334])	0,138	0,087
	AC_4	QMS	LHS	LHS	ES	LMS	([0,444;0,522]|[0,410;0,487]|[0,251;0,317])	0,190	
	AC_5	MS	HS	HS	LHS	ES	([0,548;0,639]|[0,311;0,378]|[0,234;0,297])	0,229	
	AC_1	ES	QHS	QHS	HS	LHS	([0,659;0,759]|[0,219;0,278]|[0,208;0,263])	0,272	
	AC_2	QMS	ES	LMS	MS	QMS	([0,290;0,336]|[0,618;0,720]|[0,226;0,296])	0,120	
DM 3	AC_3	QMS	LHS	ES	LMS	LMS	([0,384;0,451]|[0,480;0,568]|[0,251;0,318])	0,167	0,096
	AC_4	MS	HS	LHS	ES	LMS	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,204	
	AC_5	LMS	QHS	LHS	LHS	ES	([0,562;0,658]|[0,297;0,365]|[0,239;0,299])	0,237	

Table 7.14. Pairwise comparison of aircrafts for the criterion: C_{T6}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
	AC_1	ES	QHS	EHS	HS	LHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,281	
	AC_2	QMS	ES	LHS	LMS	LMS	([0,384;0,451]|[0,480;0,568]|[0,251;0,318])	0,164	
DM 1	AC_3	EMS	LMS	ES	QMS	QMS	([0,280;0,325]|[0,653;0,755]|[0,210;0,284])	0,108	0,064
	AC_4	MS	LHS	QHS	ES	ES	([0,550;0,638]|[0,346;0,423]|[0,244;0,315])	0,222	
	AC_5	LMS	LHS	QHS	ES	ES	([0,553;0,641]|[0,334;0,411]|[0,250;0,319])	0,224	
	AC_1	ES	EHS	EHS	LHS	HS	([0,727;0,849]|[0,186;0,247]|[0,169;0,235])	0,294	
	AC_2	EMS	ES	ES	MS	MS	([0,353;0,400]|[0,592;0,695]|[0,241;0,327])	0,132	
DM 2	AC_3	EMS	ES	ES	MS	MS	([0,353;0,400]|[0,592;0,695]|[0,241;0,327])	0,132	0,078
	AC_4	LMS	HS	HS	ES	LHS	([0,551;0,642]|[0,301;0,367]|[0,241;0,302])	0,230	
	AC_5	MS	HS	HS	LMS	ES	([0,508;0,594]|[0,365;0,441]|[0,234;0,299])	0,211	
	AC_1	ES	QHS	HS	LHS	LHS	([0,616;0,714]|[0,243;0,301]|[0,229;0,285])	0,262	
	AC_2	QMS	ES	LMS	MS	MS	([0,295;0,343]|[0,601;0,702]|[0,232;0,302])	0,127	
DM 3	AC_3	MS	LHS	ES	LMS	LMS	([0,388;0,455]|[0,467;0,554]|[0,256;0,323])	0,173	0,039
	AC_4	LMS	HS	LHS	ES	ES	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,219	
	AC_5	LMS	HS	LHS	ES	ES	([0,516;0,596]|[0,354;0,430]|[0,262;0,334])	0,219	

Table 7.15. Pairwise comparison of aircrafts for the criterion: C_{E1}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	QHS	EHS	QHS	HS	([0,728;0,839]|[0,183;0,242]|[0,169;0,231])	0,296	0,072
	AC_2	QMS	ES	LHS	ES	LMS	([0,430;0,495]|[0,461;0,550]|[0,263;0,341])	0,177	
	AC_3	EMS	LMS	ES	LMS	MS	([0,299;0,346]|[0,596;0,698]|[0,234;0,306])	0,126	
	AC_4	QMS	ES	LHS	ES	LMS	([0,430;0,495]|[0,461;0,550]|[0,263;0,341])	0,177	
	AC_5	MS	LHS	HS	LHS	ES	([0,523;0,612]|[0,326;0,392]|[0,245;0,308])	0,223	
DM 2	AC_1	ES	EHS	QHS	LHS	LHS	([0,681;0,798]|[0,211;0,272]|[0,197;0,258])	0,277	0,088
	AC_2	EMS	ES	LMS	MS	QMS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_3	QMS	LHS	ES	MS	LMS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	
	AC_4	LMS	HS	HS	ES	LHS	([0,551;0,642]|[0,301;0,367]|[0,241;0,302])	0,230	
	AC_5	LMS	QHS	LHS	LMS	ES	([0,524;0,615]|[0,348;0,425]|[0,240;0,302])	0,217	
DM 3	AC_1	ES	EHS	QHS	HS	LHS	([0,696;0,810]|[0,202;0,262]|[0,188;0,250])	0,282	0,083
	AC_2	EMS	ES	LMS	MS	QMS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,114	
	AC_3	QMS	LHS	ES	LMS	MS	([0,379;0,446]|[0,496;0,585]|[0,243;0,312])	0,161	
	AC_4	MS	HS	LHS	ES	LMS	([0,479;0,562]|[0,381;0,458]|[0,245;0,310])	0,202	
	AC_5	LMS	QHS	HS	LHS	ES	([0,584;0,681]|[0,284;0,351]|[0,229;0,289])	0,241	

Table 7.16. Pairwise comparison of aircrafts for the criterion: C_{E2}

		AC_1	AC_2	AC_3	AC_4	AC_5	w_s	w_s	CR
DM 1	AC_1	ES	EHS	ES	HS	QHS	([0,690;0,802]|[0,227;0,296]|[0,198;0,265])	0,284	0,002
	AC_2	EMS	ES	QMS	MS	LMS	([0,286;0,332]|[0,634;0,736]|[0,218;0,291])	0,117	
	AC_3	ES	QHS	ES	HS	LMS	([0,576;0,665]|[0,320;0,397]|[0,240;0,308])	0,238	
	AC_4	MS	HS	MS	ES	ES	([0,463;0,534]|[0,443;0,532]|[0,249;0,328])	0,190	
	AC_5	QMS	LHS	QMS	ES	ES	([0,422;0,487]|[0,491;0,580]|[0,250;0,331])	0,172	
DM 2	AC_1	ES	QHS	QHS	HS	HS	([0,675;0,774]|[0,210;0,268]|[0,199;0,254])	0,278	0,10
	AC_2	QMS	ES	ES	MS	MS	([0,357;0,404]|[0,577;0,679]|[0,248;0,331])	0,139	
	AC_3	QMS	ES	ES	MS	MS	([0,357;0,404]|[0,577;0,679]|[0,248;0,331])	0,139	
	AC_4	MS	HS	HS	ES	ES	([0,539;0,621]|[0,350;0,427]|[0,245;0,318])	0,222	
	AC_5	MS	HS	HS	ES	ES	([0,539;0,621]|[0,350;0,427]|[0,245;0,318])	0,222	
DM 3	AC_1	ES	EHS	EHS	QHS	LHS	([0,744;0,864]|[0,176;0,237]|[0,159;0,225])	0,297	0,077
	AC_2	EMS	ES	ES	LMS	QMS	([0,355;0,401]|[0,589;0,692]|[0,243;0,329])	0,132	
	AC_3	EMS	ES	ES	LMS	QMS	([0,355;0,401]|[0,589;0,692]|[0,243;0,329])	0,132	
	AC_4	QMS	LHS	LHS	ES	MS	([0,439;0,518]|[0,424;0,501]|[0,243;0,311])	0,185	
	AC_5	LMS	QHS	QHS	HS	ES	([0,633;0,732]|[0,257;0,324]|[0,208;0,266])	0,254	

The spherical fuzzy global priority weights are computed by utilising the equation 16 which is used to weight the decision matrix in each previous tables. Table 7.17 demonstrate the global weights.

$$\tilde{a}_{S_{ij}} = \overline{\omega}_j^S . \tilde{a}_{S_i},$$

$$\tilde{a}_{S_{ij}} = \left\{ \begin{aligned} & \left[\left(1-\left(1-\alpha_{S_i}^2\right)^{\overline{\omega}_j^S}\right)^{\frac{1}{2}}, \left(1-\left(1-b_{S_i}^2\right)^{\overline{\omega}_j^S}\right)^{\frac{1}{2}} \right], \\ & \left[c_{S_i}^{\overline{\omega}_j^S}, d_{S_i}^{\overline{\omega}_j^S} \right], \\ & \left[\begin{aligned} & \left(\left(1-\alpha_{S_i}^2\right)^{\overline{\omega}_j^S} - \left(1-\alpha_{S_i}^2 - e_{S_i}^2\right)^{\overline{\omega}_j^S} \right)^{\frac{1}{2}}, \\ & \left(\left(1-b_{S_i}^2\right)^{\overline{\omega}_j^S} - \left(1-b_{S_i}^2 - f_{S_i}^2\right)^{\overline{\omega}_j^S} \right)^{\frac{1}{2}} \end{aligned} \right] \end{aligned} \right\} \qquad (16)$$

Table 7.17. Final spherical fuzzy global priority weights

	SC_{F1}	SC_{F2}	SC_{F3}	SC_{F4}	SC_{T1}	SC_{T2}	SC_{T3}	SC_{T4}	SC_{T5}	SC_{T6}	SC_{E1}	SC_{E2}
AC_1	([0,403;0,468], [0,602; 0,662], [0,197; 0,271])	([0,153; 0,183], [0,898; 0,921], [0,103; 0,137])	([0,330; 0,399], [0,709; 0,747], [0,137; 0,191])	([0,265; 0,321], [0,805; 0,832], [0,111; 0,157])	([0,313; 0,378], [0,733; 0,772], [0,135; 0,187])	([0,226; 0,267], [0,839; 0,867], [0,125; 0,171])	([0,226; 0,286], [0,881;0,899], [0,073; 0,121])	([0,397; 0,492], [0,660; 0,706], [0,124; 0,196])	([0,199; 0,237], [0,834; 0,870], [0,133; 0,176])	([0,397; 0,492], [0,660; 0,706], [0,124; 0,196])	([0,561; 0,675], [0,427; 0,492], [0,146; 0,226])	([0,526; 0,635], [0,477; 0,544], [0,166; 0,249])
AC_2	([0,247;0,281], [0,770; 0,830], [0,179; 0,242])	([0,228; 0,270], [0,847; 0,874], [0,116; 0,162])	([0,269; 0,318], [0,777; 0,815], [0,148; 0,201])	([0,207; 0,250], [0,844; 0,868], [0,118; 0,157])	([0,194; 0,231], [0,841; 0,876], [0,130; 0,173])	([0,181; 0,216], [0,877; 0,904], [0,107; 0,145])	([0,158; 0,192], [0,922; 0,936], [0,077; 0,108])	([0,142; 0,166], [0,901; 0,935], [0,107; 0,150])	([0,397; 0,492], [0,660; 0,706], [0,124; 0,196])	([0,202; 0,240], [0,827; 0,864], [0,137; 0,181])	([0,312; 0,362], [0,679; 0,741], [0,198; 0,264])	([0,204; 0,238], [0,796; 0,858], [0,158; 0,214])
AC_3	([0,247;0,281], [0,770; 0,830], [0,179; 0,242])	([0,215; 0,255], [0,853; 0,879], [0,119; 0,164])	([0,197; 0,234], [0,831; 0,867], [0,136; 0,179])	([0,185; 0,222], [0,864; 0,888], [0,115; 0,152])	([0,144; 0,169], [0,893; 0,927], [0,113; 0,154])	([0,239; 0,283], [0,833; 0,862], [0,122; 0,169])	([0,080; 0,094], [0,967; 0,978], [0,062; 0,086])	([0,199; 0,237], [0,834; 0,870], [0,133; 0,176])	([0,300; 0,359], [0,732; 0,771], [0,142; 0,193])	([0,145; 0,169], [0,895; 0,930], [0,111; 0,154])	([0,214; 0,248], [0,772; 0,835], [0,171; 0,226])	([0,427; 0,503], [0,565; 0,630], [0,190; 0,258])
AC_4	([0,403;0,468], [0,602; 0,662], [0,197; 0,271])	([0,116; 0,136], [0,929; 0,951], [0,092; 0,125])	([0,269; 0,318], [0,777; 0,815], [0,148; 0,201])	([0,124; 0,144], [0,916; 0,939], [0,104; 0,135])	([0,388; 0,482], [0,673; 0,718], [0,122; 0,193])	([0,303; 0,380], [0,776; 0,808], [0,110; 0,170])	([0,111; 0,132], [0,946; 0,958], [0,075; 0,100])	([0,281; 0,339], [0,767; 0,807], [0,135; 0,185])	([0,151; 0,176], [0,882; 0,918], [0,120; 0,162])	([0,299; 0,356], [0,759; 0,800], [0,144; 0,201])	([0,312; 0,362], [0,679; 0,741], [0,198; 0,264])	([0,337; 0,393], [0,666; 0,729], [0,189; 0,257])
AC_5	([0,403;0,468], [0,602; 0,662], [0,197; 0,271])	([0,302; 0,379], [0,788;0,819], [0,102; 0,162])	([0,148; 0,173], [0,884;0,918], [0,120; 0,159])	([0,157; 0,187], [0,890;0,914], [0,109; 0,144])	([0,250; 0,299], [0,788;0,824], [0,136; 0,183])	([0,119; 0,139], [0,927;0,950], [0,093; 0,127])	([0,181; 0,220], [0,905;0,920], [0,080; 0,113])	([0,352; 0,441], [0,706;0,751], [0,129; 0,197])	([0,256; 0,306], [0,779;0,816], [0,139; 0,187])	([0,301; 0,358], [0,752;0,794], [0,148; 0,205])	([0,384; 0,458], [0,571;0,626], [0,189; 0,250])	([0,306; 0,356], [0,701;0,761], [0,188; 0,255])

The ranking of alternatives is done according to their scores which are shown in Table 7.18. Here, A350-900 has the highest score and ranked first. B787-9 follows it and ranked as second. A330-300 has the lowest score. According to the result, A350-900 type aircraft is chosen as the most appropriate option among the other alternatives.

Table 7.18 Score values and rankings of alternatives

Aircraft Options	Scores	Ranks
AC_1 - A350-900	0.2224	1
AC_2 - A330-200	0.1921	4
AC_3 - A330-300	0.1851	5
AC_4 - B777-300ER	0.1968	3
AC_5 - B787-9	0.2036	2

8. SENSITIVITY ANALYSIS

Sensitivity analysis is applied to understand how potential alterations in the weights of sub-criteria can affect the process of aircraft selection. While performing sensitivity analysis, the linguistic values were increased by one unit for the relevant criterion and kept constant for other criteria. Here, the linguistic expressions in pairwise comparison matrices are changed with one-unit upper for each criterion and the impacts of these changes are recorded.

While conducting sensitivity analysis, it is seen that changes in some of the criteria is making CR above 10%. Hence, the analysis is done only with five sub-criteria that do not increase CR which are C_{11} (direct operating cost), C_{12} (purchasing cost), C_{21} (seat capacity), C_{22} (belly capacity), and C_{24} (reliability). Table 8.1 and Figure 8.1-8.5 demonstrate the sensitivity analysis results.

Table 8.1. The impacts of change in criterion

Criterion	Impact %
C_{21} (seat capacity)	4,58%
C_{11} (direct operating cost)	4,00%
C_{24} (reliability)	2,55%
C_{12} (purchasing cost)	1,32%
C_{22} (belly capacity)	1,08%

It is observed that seat capacity (with 4.58%) and direct operating cost (with 4,00%) are the most impactful sub-criteria while belly capacity (with 1.08%) is the least influential sub-criteria on the final result. In other words, the most sensitive criteria for the aircraft selection are seat capacity and direct operating cost of an aircraft. Airlines companies focus more on cost and seat capacity and less on belly capacity when they need to add a new aircraft in their fleet.

Figure 8.1. SC11 Sensitivity

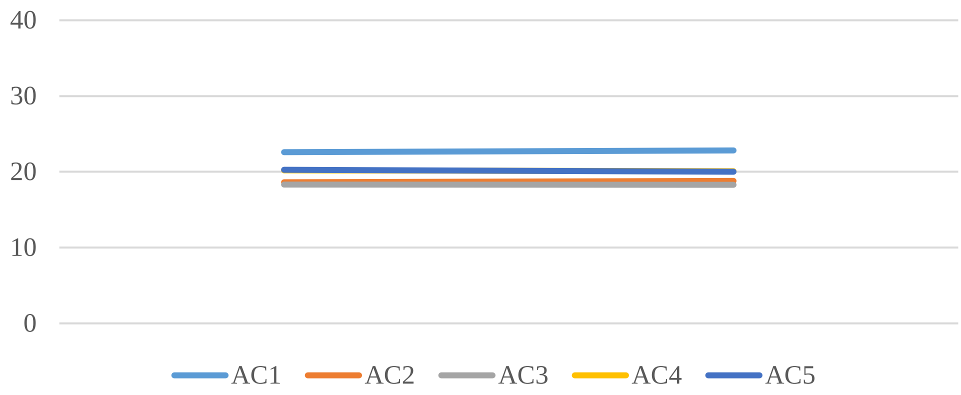


Figure 8.2. SC12 Sensitivity

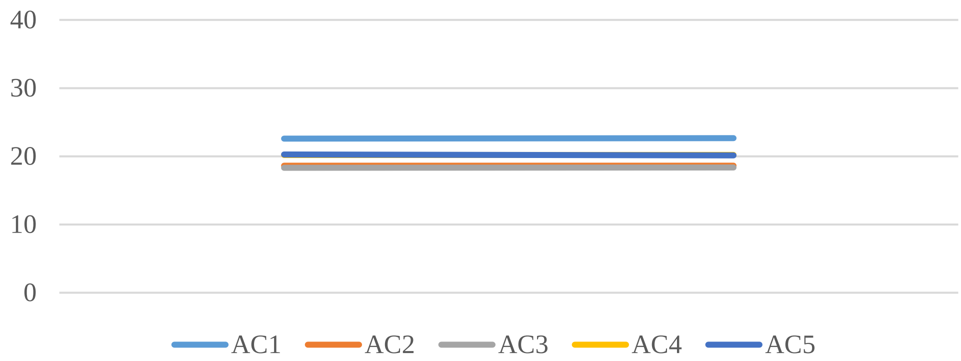


Figure 8.3. SC21 Sensitivity

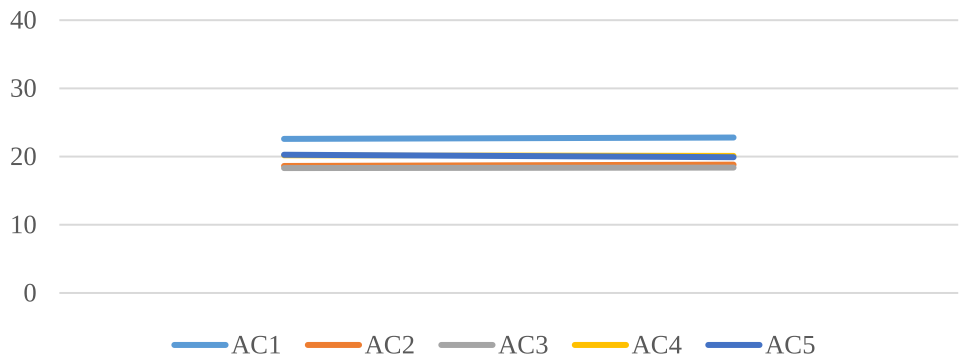


Figure 8.4. SC22 Sensitivity

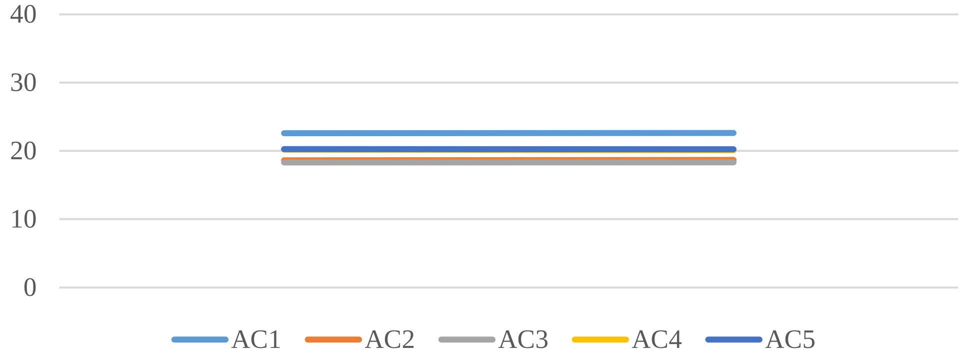
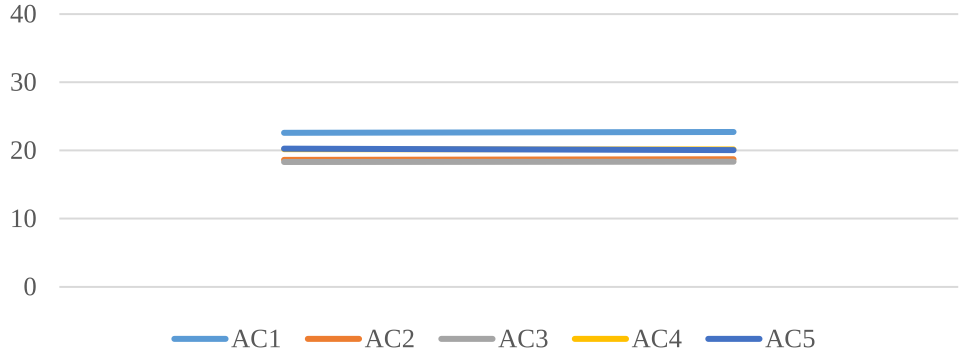


Figure 8.5. SC24 Sensitivity



9. CONCLUSION

Air travel has a crucial role in modern transportation, offering advantages such as speed, easiness, and accessibility for both domestic and international travel. Air travel has transformed the way people and goods move around the world, facilitating global connectivity, economic growth, and cultural exchange.

As the air traffic has a tendency of growth, airline companies need to meet the increasing demand and widen their fleet in order to remain competitive. Therefore, fleet planning and aircraft selection become crucial issues for airlines. Selecting an appropriate aircraft helps airlines to enhance their profit and meet the industry standards.

Since aircraft selection is a complex decision-making process that contains multiple criteria, MCDM methods are one way to handle this complexity. In this study, we have proposed the method of interval- valued spherical fuzzy analytic hierarchy process which handles uncertainty and ambiguity in the decision-making process to evaluate aircrafts. This method allows decision makers to state their opinions and choices in a flexible way. In this study, the three main criteria which are financial aspects, technical aspects, and environmental aspects and twelve sub-criteria (direct operating cost, purchasing cost, maintenance cost, delivery time, seat capacity, belly capacity, range, reliability, fuel consumption, lifespan of aircraft, CO_2 emission and noise) are defined. Direct operating cost includes fuel expense, ownership cost, handling expenses, and crew fees. Purchasing cost is the list price of the aircraft. Maintenance cost is the cost of repair, overhaul on engines and components, modification, inspection, and condition determination. Delivery time is the time that manufacturer can deliver the aircraft. Seat capacity refers the maximum number of seat that an aircraft can have. Belly capacity is the capacity allocated in passenger aircraft for freight and baggage. Range is the maximum distance that an aircraft can fly. Reliability is defined as the consistent and presumable performance of an aircraft without unforeseen failures in a given time period. Fuel consumption is the amount of fuel that an aircraft consumes during flight. Lifespan of aircraft refers to the number of years that an aircraft can be operated. CO_2 emission is the release of CO_2 into the atmosphere causing by the burn of aviation fuel during flight. Noise is the sound produced by aircraft engines and other mechanical components during take-off, flight, and landing, which can affect the surrounding environment and communities near airports.

We focused on wide-body aircraft alternatives and evaluated them under the criteria that we selected. A350-900, A330-200, A330-300, B777-300ER and B787-9 are selected as alternatives. Three decision-makers filled the pairwise comparison matrices by using linguistic expressions. Afterwards, these linguistic expressions transformed into interval valued spherical fuzzy numbers. Then, the weights of criteria are calculated by using these fuzzy numbers in related formulas. After applying the proposed method, result shows that A350-900 is the most appropriate alternative and B787-9 becomes the second option.

For future studies, other MCDM methods under spherical fuzzy sets can be used to solve aircraft selection problems. Also, the effectiveness of spherical fuzzy AHP can be compared with other MCDM methods such as traditional AHP, TOPSIS, and ELECTRE in future studies.

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