MULTI CRITERIA DECISION MAKING APPROACH FOR THE BEST AIRCRAFT MODEL SELECTION FOR FOREST FIREFIGHTING IN TÜRKIYE

A THESIS SUBMITTED TO

THE SCHOOL OF GRADUATE STUDIES

OF

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION

BY

ROBERT MUTABARUKA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
AVIATION MANAGEMENT

AUGUST 2024

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Approval of the thesis:

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I hereby affirm that all information contained in this document has been acquired and presented in compliance with academic standards and ethical practices. I further affirm that, as mandated by these standards and practices, I have thoroughly cited and referenced all materials and findings that are not original to this work.

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ABSTRACT

MULTI CRITERIA DECISION MAKING APPROACH FOR THE BEST AIRCRAFT MODEL SELECTION FOR FOREST FIREFIGHTING IN TÜRKİYE

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Master of Science, Aviation Management
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Forests in the World play a vital role in maintaining ecological balance, supporting biodiversity, and providing economic resources. However, there is significant threat with the increasing risk of wildfires. Forest firefighting is critical particularly during the dry season.

This study aims to select the most suitable aircraft models for combating wildfires in the regions in order to enhance the efficiency and effectiveness of firefighting operations Aircraft play a vital role in wildfire suppression due to their ability to rapidly deploy resources to inaccessible areas. In this study, a model was created to select the most suitable aircraft to be used in forest fires, taking into consideration of regions' features.

The methodology used for the model is multicriteria decision making approach which integrates the Analytic Hierarchy Process (AHP) for expert judgment consistency checks, weighting the criteria combined with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Multi-Objective Optimization by Ratio Analysis (MOORA) methods u to evaluate and rank the alternatives.

Five aircraft models which are Canadair CL-215, Canadair CL-415, Air Tractor "Fire Boss," Lockheed C-130 Hercules, and Beriev Be-200 were analyzed according to the model which includes three main criteria and seven subcriteria.

The findings reveal that the Canadair CL-415 is ranked first, followed by the Air Tractor "Fire Boss," and Beriev Be-200. These top-performing aircraft excelled in payload capacity, amphibious structure, maneuverability, and engine capabilities.

For this study, Turkiye’s geographic characteristics and climatic conditions have been taken into consideration to evaluate the aircraft models. This study taking into account the regional characteristics, will provide strategic insights for enhancing wildfire management efforts, contributing to improved safety and protection of natural resources.

Keywords: Forest Firefighting, Aircraft Selection, MCDM, Fuzzy Logic

ÖZ

TÜRKİYE'DE ORMAN YANGINLARIYLA MÜCADELE İÇİN EN İYİ UÇAK MODELİNİN SEÇİMİ İÇİN ÇOK KRİTERLİ KARAR VERME YAKLAŞIMI

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Dünyadaki ormanlar, ekolojik dengeyi koruma, biyolojik çeşitliliği destekleme ve ekonomik kaynak sağlama açısından hayati bir rol oynamaktadır. Ancak, orman yangınlarının artan riski önemli bir tehdit oluşturmaktadır. Orman yangınlarıyla mücadele, özellikle kurak mevsimde kritik öneme sahiptir.

Bu çalışma, bölgedeki orman yangınlarıyla mücadelede operasyonların verimliliğini ve etkinliğini artırmak için en uygun uçak modellerinin seçimini amaçlamaktadır.

Uçaklar, erişilemeyen bölgelere hızla kaynak aktarma yetenekleri nedeniyle orman yangınlarının bastırılmasında hayati bir rol oynamaktadır.

Bu çalışmada, bölgelerin özellikleri gözönüne alınarak orman yangınlarında kullanılabilecek en uygun uçak modelinin seçimi için bir model oluşturulmuştur.

Çalışmada model için kullanılan yöntem kriterlerin ağırlıklandırılmasında AHP ve alternatiflerin değerlendirilmesinde ve sıralamasında TOPSIS ve MOORA yöntemlerinin birleştirildiği çok kriterli karar verme yaklaşımı olup, bulanık mantık uygulaması kullanılmıştır.

Üç ana kriter ve yedi alt kriterden oluşan modelde, Air Tractor "Fire Boss, Beriev Be-200, Canadair CL-215, Canadair CL-415, " Lockheed C-130 Hercules'den oluşan alternatifler analiz edilmiştir.

Değerlendirmede Canadair CL-415 ilk sırada yer almış olup, onu Air Tractor "Fire Boss," ve Beriev Be-200 izlemiştir.

Bu çalışmada uçak modellerinin değerlendirilmesinde örnek çalışma olarak Türkiye'nin coğrafik ve iklimsel özellikleri göz önüne alınmıştır. Bölgesel özellikleri dikkate alan bu çalışma yangınla mücadelelerde ve ve doğal kaynakların zarar görmeden korunmasında stratejik etkili kararların önemini ortaya koyabilecektir.

Anahtar Kelimeler: Orman Yangınlarıyla Mücadele, Uçak Seçimi, Çok Kriterli Karar Verme (ÇKKV), Bulanık Mantık

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LIST OF ABBREVIATION

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ARAS	Additive Ratio Assessment
CI	Consistency Index
CN	Crisp Number
CR	Consistency Ratio
DOD	Department of Defense
EWM	Entropy weight method
FL	Fuzzy Logic
FN	Fuzzy Number
FS	Fuzzy Set
FUCOM	Full Consistency Method
GDF	General Directorate of Forestry
GMT	Greenwich Mean Time
LAT	Large Air-tankers
MAFFS	Military Airborne Firefighting System
MCDM	Multiple Criteria Decision Making
MCDMA	Multiple Criteria Decision Making Analysis
MOORA	Multi-Objective Optimization by Ratio Analysis
OGM	Orman Genel Müdürlüğü (Forest management)
PPE	Personal Protective Equipment
RI	Random Index
SEAT	Single Engine Air-tankers
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UAVs	Unmanned Aerial Vehicles
USFS	United State Fire Service
VLAT	Very Large Air-tankers
VPAF	Vietnam People’s Air Force

LIST OF SYMBOLS

"P_i"	Performance Score
$P_n(X)$	The Membership Function
A^-	The worst value
A^+	The best value
S_i^-	Euclidean distance from the ideal worst
S_i^+	Euclidean distance from the ideal best
Y_i	Ratio Score
$\sum_{j \epsilon J_{benefit}} X_{ij}$	The normalized values for Beneficial Criteria
$\sum_{j \epsilon J_{cost}} X_{ij}$	The normalized values for Non-Beneficial Criteria
"r_{ij}"	Normalized matrix
"a"	Alternatives
"C"	Criteria
"V_{ij}"	Weighted Normalized matrix
D	The decision matrix
W	Weight
λmax	The Priority Vector

CHAPTER 1

INTRODUCTION

Aviation activities play a crucial role in various sectors, facilitating rapid and efficient transportation of goods, passengers, and resources. Among the diverse applications of air transportation, aerial firefighting activities stand out as a critical and indispensable component. The intersection of aviation and firefighting introduces a specialized category of aircraft designed explicitly for combating wildfires, known as aerial firefighting aircraft.

Wildfires are becoming more frequent, intense, and widespread globally, largely due to climate change. This has extended wildfire seasons and increased the areas affected. Aircraft designed or adapted for aerial firefighting are crucial in combating these fires.

The escalating frequency and intensity of wildfires worldwide have increased the significance of aerial firefighting activities. These specialized aircraft contribute significantly to the involvement and suppression of wildfires, mitigating their destructive impact on ecosystems, communities, and valuable resources. The intersection of aviation and firefighting presents a unique set of challenges and opportunities, demanding the selection of optimal aircraft models equipped to handle the complexities of airborne firefighting operations.

In Türkiye, wildfires are particularly common during the dry season (months from May to October). The country's rich forest cover, home to diverse flora and fauna, makes it vulnerable to fires, especially in areas inaccessible by road. This vulnerability underscores the importance of developing an effective aerial firefighting fleet. Fleet planning for aerial firefighting is complex, involving considerations of technologies, economics, market analysis, performance, finance, and environmental impact.

The study aims to identify the most suitable aircraft models for forest firefighting which is fundamental to enhancing the efficiency and effectiveness of forest firefighting operations and improving overall wildfire management in Türkiye. The study also forms the basis for recommendations and choices, significantly influencing tenders and the preservation of priceless natural resources.

In the literature, many studies have been performed for different fields of the air transport sector on aircraft selection. In these studies, mainly Multi-criteria Decision Making (MCDM) applications were used decision support models were studied on the selection of fighter aircraft, trainer aircraft, aircraft for the general aviation sector, and passenger aircraft and cargo aircraft for commercial airline companies.

This study covers the problem of selecting the best aircraft for forest firefighting, which is a complex, and critical task that involves evaluating various models based on multiple criteria. The diversity of aircraft, each with unique strengths and weaknesses, necessitates a systematic approach to determine which models are most effective in different firefighting scenarios. The decision-making process must consider some factors such as technical performance, operational costs, aircraft structure and specific firefighting aircraft capabilities.

The study is structured into seven comprehensive chapters to systematically address the research topic and findings. The Introduction provides general information about the study. Chapter 2, titled Fires, offers an overview of fires in Türkiye, discussing forest fire statistics, methodologies, and materials used in firefighting, strategies for suppression, and aerial firefighting with fixed-wing aircraft and helicopters. Chapter 3 which is the Literature Review examines academic and practical studies on fires, criteria for selecting firefighting aircraft, and solutions to forest fire challenges. Chapter 4 is the Methodology which introduces Multi-Criteria Decision Making (MCDM) methods, including the Analytic Hierarchy Process (AHP) for weighting criteria and evaluation methods like Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and MOORA, and discusses the application of fuzzy concepts in MCDM. Chapter 5 focuses on selecting the best aircraft model for forest firefighting in Türkiye, outlining study objectives, significance, criteria, alternatives, data and limitations. Chapter 6 which is Results and Discussion present findings, including consistency check results for the AHP method, FAHP weighting results, and evaluation results from TOPSIS and MOORA methods integrated with FAHP, with a detailed discussion of these results. Chapter 7 is the final chapter, Conclusion and Recommendation, summarizes the research findings, presents Conclusions, and offers Recommendations based on the study's results.

CHAPTER 2

FIRES

2.1 General

The rapid oxidation of a substance (the fuel) during the exothermic chemical mechanism of combustion, which emits heat, light, and other reaction products, is known as fire (Smith, 2022). Flames are created at a specific stage of the combustion reaction designated as the ignition point. The component of the fire that is visible is the flame.

Fire is an important phenomenon that affects ecological systems all over the World. Its negative impacts include danger to people, other living creatures and property, air pollution, and water contamination, while its good benefits include promoting growth and preserving a variety of ecological systems.

2.1.1 Fire Types

Fires can be classified into various types based on their origin, behavior, and the materials involved. Common fire types include:

a. ***Wildfires*****:** is an uncontrolled fire that burns quickly across vegetation, such as forests, grasslands, and shrubby areas. It is sometimes referred to as a blaze or forest fire. It is characterized by a quick spread, driven by wind, dry conditions, and flammable vegetation. They can exhibit high intensity, causing significant damage to ecosystems and wildlife, commonly cause by lightning strikes, human activities, or a combination of both. According to the area or the country, there are the ways to manage and to prevent it, like firebreaks by creating barriers to prevent the fire's progress, controlled burns by reducing fuel load and preventing larger wildfires and early detection by using technology and surveillance for early fire detection (Jones & Brown, 2021).

b. ***Structural Fires*****:** are the ones that occur within buildings or other structures, involving the combustion of materials within those structures. They typically start within residential, commercial, or industrial buildings.

c. ***Urban Fires*****:** refer to large-scale fires affecting urban areas, including cities and densely populated regions, they can result in significant damage to buildings, infrastructure, and livelihoods. While designing cities, urban planning should be made carefully against to this type of fires and buildings should be constructed with fire-resistant materials and urban planning studies should include layouts for emergency response plans with efficient firefighting services and educating residents on fire safety in urban environments.

d. ***Industrial Fires*****:** are the ones involving industrial facilities and processes, often fueled by flammable materials used in manufacturing or storage. They originate within industrial plants, warehouses, or storage areas with chemical risks involving the combustion of hazardous materials, posing additional risks which can lead to environmental pollution and damage to industrial infrastructure. The way to manage and to prevent this kind of fire includes strict adherence to safety protocols and regulations, installation of firefighting equipment and systems and employee training on fire safety measures and emergency response.

e. ***Grass Fires:*** are the fires that primarily burn grass and low vegetation, often occurring in open areas. Grass fires, fueled by dry grass, leaves, and low-lying vegetation, have the potential for rapid spread, especially in dry and windy conditions, impacting wildlife habitats and ecosystems. Management and prevention strategies include creating firebreaks, clearing dry vegetation, maintaining increased awareness during dry seasons and implementing controlled burns to reduce fuel loads. These measures collectively contribute to effective grass fire prevention and management.

2.2 Forest Fire

The idea of fire tracing back approximately 440 million years to the Silurian epoch (Keeley, Bond , Bradstock , Pausas, & Rundel, 2012) is crucial in understanding terrestrial ecosystems and their development. Fire science explains the occurrence of fire through the "fire triangle," which includes combustible material, oxygen, and temperature (Çanakçıoğlu, 1993). However, these elements are better understood as conditions necessary for ignition, leading to alternative terms like "ignition triangle" or "combustion triangle."

Fire plays a natural role in the cycle of forest ecosystems, leading to the development of fire ecology. This field studies the causes like a conflagration that can begin accidentally or be intentionally created (arson), their impacts on the environment, and the dynamics of ecosystems post-fire.

Fires have both beneficial and detrimental impacts. As the beneficial impacts are those such as boosting growth and preserving different biological systems, water poisoning, air pollution, and danger to life and property are some of its detrimental effects. With the increasing likelihood of more frequent and larger forest fires in the future due to factors like population density and climate change, understanding these dynamics is crucial. Human activities and climate change significantly contribute to the occurrence and severity of these fires.

2.2.1 Forest Fires in Turkiye

One of the countries suffering forest fires is Turkiye. Forest fire management in Türkiye is carried out by state forest enterprises operating under regional directorates. However, fire data occurring in areas such as national parks and nature parks, which are under the responsibility of the Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks, are classified under a separate general directorate. The General Directorate of Forestry's (GDF) commitment to providing accurate and detailed statistical information aids in formulating strategies for effective fire prevention and management, contributing to the preservation of Türkiye's valuable ecosystems.

In Turkiye, the severe forest fires have been seen since 1970s. As shown below in the Table 1 since 1970, Türkiye's Largest Forest Fires in different location as reported by Orman Genel Müdürlüğü (OGM).

Table 1: Türkiye's Largest Forest Fires

Rank	**Year**	**Location**	**Burned Area (ha)**
1	2021	Antalya (Manavgat)	26.903
2	1974	İzmir (Kemalpaşa)	18.795
3	1970	Antalya (Finike)	18.676
4	1995	Muğla (Marmaris)	18.297
5	1972	Antalya (Serik)	17.877
6	2019	Muğla (Marmaris)	16.602
7	1978	İzmir (Ödemiş)	15.855
8	1989	Antalya (Kumluca)	15.767
9	2008	Antalya (Taşağıl-Karabük)	15.795
10	1990	İzmir (Kemalpaşa)	14.501
11	2008	İzmir (Urla)	14.379
12	2021	Muğla (Dalaman)	14.254
13	1973	Antalya (Kemer)	14.182
14	1976	Muğla (Marmaris)	14.138
15	1979	Muğla (Köyceğiz)	14.107
16	1986	Çanakkale (Ayvacık)	13.727
17	2022	Muğla (Bördübet)	13.604
18	1972	Antalya (Kumluca)	13.578
19	1982	Antalya (Kumluca)	13.271
20	1976	İçel (Erdemli)	13.200

Source: (Kavgacı & Başaran, 2022).

Despite a decreasing trend in the total forest area burned since 1937 (except for the 2012-2021 period), the number of forest fires has steadily increased since the 1970s. As shown in Table 2 (Kavgacı & Başaran, 2022).

Table 2: Forest Fires (1937 – 2022)

Years	Number of Fires	Burned Area (ha)	Area Burned per Fire (ha)
1937-1941	2.719	92.531	34,03
1942-1951	8.298	666.586	80,33
1952-1961	8.122	263.455	32,44
1962-1971	5.803	94.080	16,21
1972-1981	10.041	167.505	16,68
1982-1991	14.216	115.853	8,15
1992-2001	21.646	140.982	6,51
2002-2011	19.739	83.638	4,24
2012-2021	27.150	226.846	8,36
Total	117.734	1.851.476	15,73

Source: (Kavgacı & Başaran, 2022).

As shown in the statistical tables, critical aspects of forest fires are detailed. Figure 1 illustrate the situation graphically.

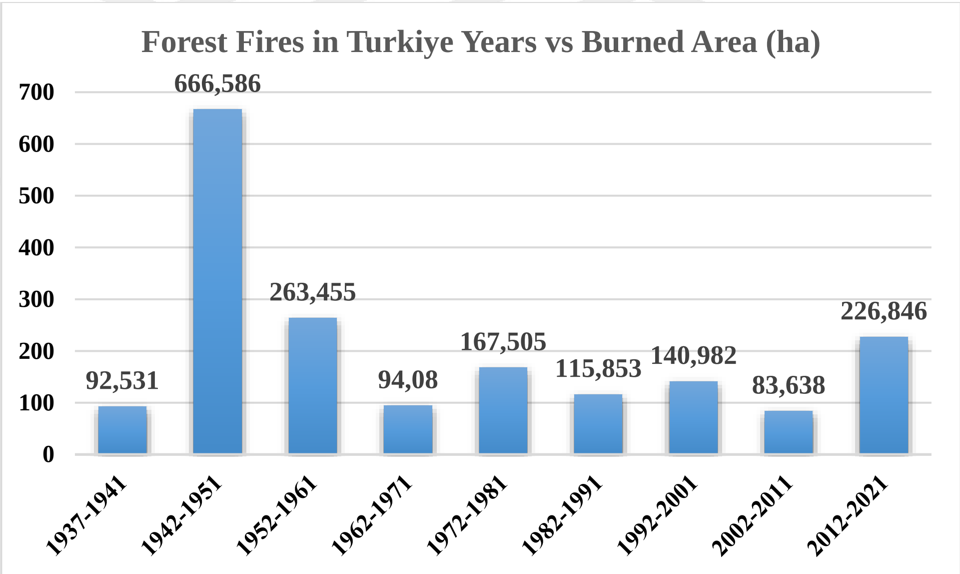

Figure 1: Forest Fires in Turkiye 1937-2022.

The statistics highlight critical aspects of forest fires, including the provinces with the most fires and the most forest area burned in the last 10 years in Table 3.

Table 3: Provinces Last 10 Years Most Forest Fires

Rank	Provinces	Number of Fires
1	Muğla	2.716
2	Antalya	2.446
3	İzmir	1.649
4	Istanbul	1.493
5	Adana	1.086
6	Manisa	962
7	Hatay	949
8	Mersin	908
9	Kastamonu	750
10	Kahramanmaraş	655

Source: (Kavgacı & Başaran, 2022).

Muğla accounts for % 10 of all fires, while Antalya follows with 1.649 fires, making up % 9. In this period, only one fire occurred in Ağrı and Iğdır, Table 4 damaging 6.61 ha in Ağrı and 0.15 ha in Iğdır.

Table 4: Provinces Last 10 Years Most Forest Area Burned

Rank	Provinces	Burned Area (ha)
1	Antalya	68.905
2	Muğla	54.507
3	Mersin	13.037
4	Hatay	12.214
5	İzmir	11.620
6	Adana	8.995
7	Osmaniye	4.896
8	Balıkesir	3.446
9	Manisa	3.337
10	Aydın	2.728

Source: (Kavgacı & Başaran, 2022).

When it is seen the Figure 2, Antalya and Muğla have the heightest burned areas, in the last year. Because Antalya and Muğla provinces have very beautiful towns and regions covered by pine forests and very desired areas from the perspective of tourism. Unfortunately, because of that those areas are crowded by travelers and accommodation facilities, most of the causes of those fires are intentional fires and negligence of humans.

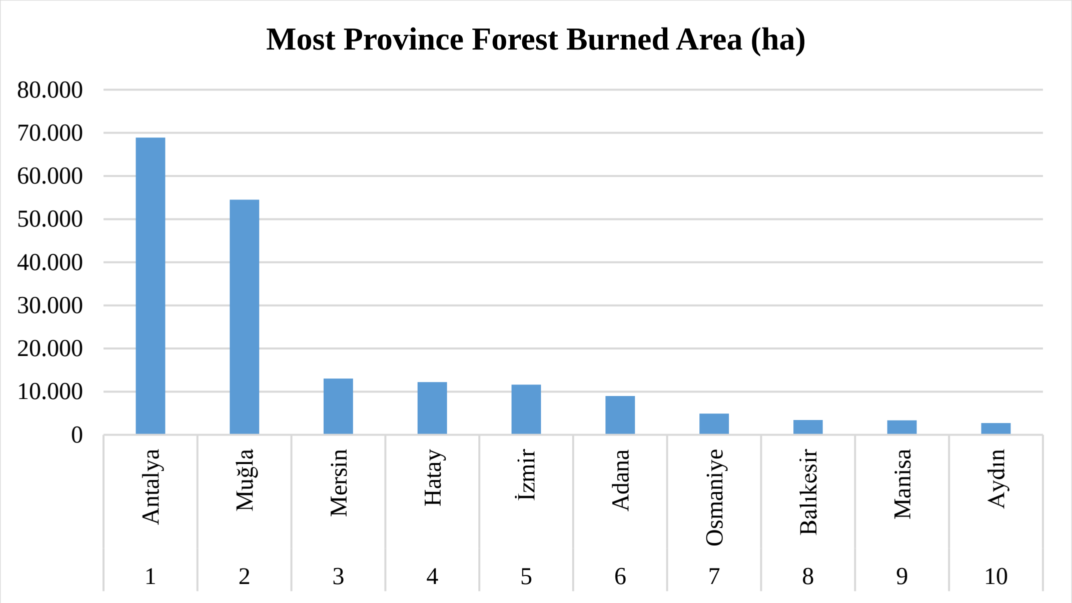

Figure 2: Most Province Forest Burnt Area in Turkiye 1937-2022

Türkiye's fire statistics from 1992 to 2022, offer a comprehensive insight into the country's forest fire dynamics as shown in the Table 5. Published by the GDF, this data not only serves as a record of the environmental impact over the years but also plays a crucial role in understanding the patterns and causes of forest fires in Türkiye.

Table 5: Forest Fires Causes (2000-2022)

Year	Causes of forest fires							
	Intentional		**Negligence-Accident**		**Natural (Lighting)**		**Unknown**	
	Number	**Hectare**	**Number**	**Hectare**	**Number**	**Hectare**	**Number**	**Hectare**
2000	410	4 417	1 384	19 017	132	167	427	2 752
2001	251	651	1 629	4 247	188	735	563	1 761
2002	218	509	809	7 287	181	261	263	457
2003	258	665	1 317	4 520	120	694	482	765
2004	242	748	1 033	3 093	128	233	359	802
2005	272	402	867	2 084	140	48	251	288
2006	166	206	1 315	5 873	330	543	416	1 139
2007	292	1 705	1 642	7 994	407	243	488	1 722
2008	377	797	1 018	26 283	330	699	410	1 970
2009	231	792	884	3 082	333	105	345	700
2010	146	526	861	1 851	281	69	573	871
2011	153	283	1 067	2 368	130	39	604	922
2012	197	1 615	936	5 780	373	334	944	2 725
2013	260	1 478	1 419	4 051	258	138	1 818	5 789
2014	127	85	801	1 682	328	77	893	1 273
2015	138	167	794	1 198	257	95	961	1 759
2016	157	240	990	5 222	310	170	1 731	3 524
2017	151	619	721	7 146	259	84	1 280	4 144
2018	92	148	693	2 216	413	141	969	3 139
2019	124	686	883	6 529	372	373	1 309	3 744
2020	72	718	1 156	8 285	312	197	1 859	11 771
2021	110	46 147	1 001	46 879	353	208	1 329	46 269
2022	86	4 722	830	5 428	358	517	886	2 132

Source: (Kavgacı & Başaran, 2022).

2.3 Forest Fire Fighting

Forest fire fighting is a complex, multi-faceted effort that requires coordination among various agencies, advanced technologies, and the dedication of trained personnel (Western Fire Chiefs, 2023). Prevention and preparedness are crucial, encompassing public awareness campaigns, vegetation management, and predictive modeling to assess fire risks. Early detection and monitoring are achieved through satellite imaging, aerial surveillance, and ground-based sensors, with Unmanned Aerial Vehicles (UAVs) providing real-time data and high-resolution imagery. Suppression techniques include direct attacks using hand tools and water hoses, as well as indirect methods like back burning and creating firebreaks. Aircraft such as water bombers and helicopters play a vital role, with UAVs enhancing operational efficiency and safety.

Effective forest fire fighting requires seamless coordination and communication among fire departments, forestry services, emergency management agencies, and government bodies, often managed through Incident Command Systems (ICS). Post-fire recovery involves assessing damage, repairing infrastructure, and implementing measures to promote vegetation regrowth and prevent soil erosion. The integration of new technologies continues to enhance the effectiveness and safety of these operations, making forest fire fighting an evolving field that adapts to the increasing challenges posed by wildfires.

2.3.1 Fire Fighting Methodologies

According to the nature of the impact on the combustion process there are two main methodologies for forest fire suppression or fighting fires (Fried & Gill, 2020) involves: indirect attack and direct attack which is direct suppression impact on the edge of the fire. The nature of the first attack equipment available, spread rates, intensity levels, and other elements all influence the approach opted for.

A. Indirect Attack

Indirect attack focuses on strategic planning and the creation of barriers to control the fire's movement. This method entails establishing a containment perimeter around the entire fire, aiming to confine it to its current location (National Wildfire Coordinating Group, 2021). This perimeter is created by clearing all vegetation down to the bare mineral soil or rock. Firefighters typically initiate the process from the coolest point of the fire, progressing to construct a fire line using excavation tools or by pre-burning the area with a drip torch. The dimensions of the fire line are determined by factors such as the fire's behavior, the terrain, and the types of fuels present. The Passive or indirect methods emphasis is on creating obstacles and modifying the environment to impede the fire's progress.

B. Direct Attack

The direct attack involves confronting the fire head-on, applying water or fire suppressants directly to the flames. Firefighters manage to control the fire's spread by eliminating one of the three essential elements for combustion: heat, oxygen, or fuel. Heat is dissipated by the application of water or fire suppressants (International Association of Fire Fighters, 2022). This attack focus on immediate and targeted action to stop the fire's advance, most of the time involves the aerial firefighting.

A comprehensive approach to forest fire fighting methodologies involve various strategies such as preventive measures, early detection, rapid response, effective containment, aerial firefighting, and community education. This multi-faceted strategy aims to safeguard ecosystems, protect communities, and mitigate the impact of wildfires (National Interagency Fire Center, 2022).

a. ***Preventive Measures*****:** Prevention is a cornerstone of forest fire management. Establishing firebreaks involves strategically creating barriers to impede the advance of fires. Controlled burns, a proactive approach, are conducted to eliminate excess vegetation, reducing potential fuel for wildfires (U.S. Forest Service, 2021).

b. ***Early Detection*****:** Timely identification of wildfires is crucial. Employing advanced surveillance systems, including aerial patrols and satellite monitoring, enhances early detection capabilities. Additionally, the installation of fire towers equipped with sensors enables the rapid identification of smoke or flames (Federal Emergency Management Agency, 2021).

c. ***Rapid Response*****:** A swift response is vital to containing wildfires in their early stages (Wildland Fire Lessons Learned Center, 2021). Mobilizing firefighting teams promptly allows for the containment of small fires before they escalate. The use of helicopters and airplanes facilitates rapid deployment of water or fire retardants to suppress emerging threats efficiently.

d. ***Fire Containment*****:** Effective containment strategies are essential. Creating fire lines through controlled burns or manual removal of vegetation helps control the fire's spread. Bulldozers and other massive equipment are essential for erecting barriers and reducing the fire's impact.

e. ***Aerial Firefighting*****:** Aerial firefighting introduces a dynamic element to wildfire management. Water bombers and air tankers are deployed to drop water or fire retardants on large wildfires, mitigating their intensity. Helicopters equipped with water buckets offer precise targeting in challenging terrains (Aerial Firefighting International, 2022).

f. ***Community Education*****:** Engaging communities in fire prevention efforts is key. Educational programs raise awareness about preventive measures. Training initiatives focus on evacuation procedures and the creation of defensible spaces around properties, empowering communities to actively participate in their own safety (Firewise USA, 2021).

2.3.2 Materials Used

Materials used in forest fire fighting play a crucial role in combating wildfires effectively. These materials are selected to address various aspects of fire management, ensuring the safety of firefighting personnel and enhancing the efficiency of operations.

A. Aerial Attack

The use of water and fire suppressants is a common initial step in combating a fire, with various aircraft (fixed-wing or helicopters) involved in this process. However, extinguishing the fire is only part of the challenge. Firefighters aim to contain a wildfire before it grows uncontrollably. Fire retardants and foams are employed to slow or halt the fire's spread, giving firefighters time to move on the ground to reduce fuel, construct fire lines, and work on containing the fire (Western Fire Chiefs, 2023).

Helicopters and planes are capable of carrying buckets of water to be dumped atop the flames if there are major exposed water sources nearby. Before being dumped, the water is usually mixed with a foam retardant. In addition to insulating fuel that hasn't yet burnt, the foamed water serves as a more powerful fire barrier (Robinson, 2021)

a. ***Fire Retardants*****:** consist of Perimeter Solutions produces long-term fire retardants, foams, and gels under the Phos-Chek name (Williams & Gerald, 2007) and Chemical Retardants. Phos-Chek is a common chemical retardant used to slow down the combustion process. These retardants create a barrier on vegetation, reducing its flammability and aiding in fire control.

b. ***Water Delivery Systems*****:** These are the helicopters with water Buckets or fixed tanks. Helicopters equipped with water buckets or fixed tanks are deployed for precise water drops on targeted areas, providing a quick response to emerging fires. Air Tankers, these aircraft are capable of carrying large volumes of water or retardants, covering extensive areas and supporting ground teams.

c. ***Firefighting foams:*** Surfactants, which are artificial components that lower a liquid's surface tension, are a component of firefighting foams. These foams enhance the area that the water may soak by lowering the surface tension of the water. When it comes to putting out Class A materials, such as wood, paper, and brush, firefighters usually utilize Class A Foam.

B. Firefighting Equipment

Firefighters use a variety of equipment to fight forest fires, including hoses, pumps, chainsaws, and hand tools (Advanced systems). Firefighters also use Personal Protective Equipment (PPE) such as fire-resistant clothing, helmets, and gloves (Nibbana & Ashley, 2021).

a. *PPE*: involves flame-Resistant clothing, helmets, and gloves. Firefighters utilize specialized PPE designed to withstand high temperatures. Flame-resistant clothing, helmets, and gloves offer essential protection against heat and flames.

b. *Firebreak Tools*: Those are tools like chainsaws, bulldozers, and hand tools are essential for creating firebreaks strategic gaps in vegetation that act as barriers to put an end or minimize a wildfire's spread.

c. *Communication Systems*: Effective communication is critical in coordinating firefighting efforts. Radios and satellite communication devices enable real-time coordination among team members, ensuring a synchronized response.

d. *Surveillance Technology*: plays a key role in monitoring fire behavior using drones, satellites, and infrared cameras provide valuable data for assessing the fire's dynamics and planning effective containment strategies.

e. *Emergency Shelters*: In extreme conditions, firefighters may use fire-resistant shelters as a last resort for protection. These shelters are designed to provide refuge during intense fire conditions, offering a temporary safe haven.

2.4 Forest Fire Suppression

Forest firefighting is a complex and multifaceted challenge, requiring a combination of ground-based and aerial strategies. In aerial firefighting, aircraft are essential to the control and extinguishment of wildfires. In an area with burning vegetation, an unplanned, uncontrollable, and unpredictable fire is often referred to as a wildfire, forest fire, bushfire, wildland fire, or rural fire. Figure 3 below illustrates the dousing of a fire by a firefighting plane and trucks as smoke plumes rise from Ataturk International Airport in Istanbul, Türkiye on May 24, 2006. At around 12:30 Greenwich Mean Time (GMT), a fire that was thought to be sparked by a short circuit broke out, injuring three individuals.

Figure 3: Istanbul Airport Engulfed in Major Fire

Source: (Photo by Stringer/Getty Images).

In Türkiye, fires are categorized based on the organizational structure required for extinguishing them into four types: New, Small, Medium-sized, and Large (Erdoğan, Doganay, & Cihan, 2023).

1. New Fires: These are recently ignited fires that are in their initial stages. They typically require a rapid response to prevent them from spreading. Initial attacks often involve local firefighting teams and resources, focusing on quickly containing the fire as the below Figure 4 shows.

Figure 4: New Fire

Source: (Marc, 2015)

2. Small Fires: These fires have spread beyond the initial stage but remain manageable with a modest organizational structure. As shown in the Figure 5, they usually require additional personnel and equipment beyond the initial response team but can still be handled by local resources with some external support. A fire that can be extinguished by 1-3 teams (10-30 firefighters).

Figure 5: Small Fire

Source: (China Daily , 2020)

3. Medium-sized Fires: These fires are more extensive and complex, necessitating a more significant organizational response, including regional firefighting teams and specialized equipment. Figure 6 shows the coordination among multiple agencies becomes essential to manage the fire effectively. A fire that can be extinguished by 6-10 teams (60-100 firefighters).

Figure 6: Medium-Sized Fired

Source: (Working on Fire , 2019)

4. Large Fires: These are the most severe and widespread fires, demanding a comprehensive and large-scale organizational effort. They involve national-level coordination, extensive resources, multiple firefighting teams, aircraft support, and advanced technologies. Managing large fires often requires significant logistical planning and interagency collaboration to ensure effective containment and suppression as Figure 7 shows. Fires requiring a larger organizational structure than the team sizes mentioned above.

Figure 7: Large Fire

Source: (Stuart, 2020)

Forest fire suppression activities encompass the entire process from the moment news of a fire is received to its complete extinguishment. This process takes into account critical factors such as vegetation type, weather conditions, and topography, all of which influence the behavior and spread of the fire. The term "fire suppression" includes both "ground intervention" and "aerial intervention." Ground intervention involves direct firefighting efforts on the ground, where fire crews use tools, hoses, and other equipment to create fire lines and remove flammable materials. Aerial intervention involves the use of aircraft to drop water or fire retardant on the fire, providing support that can reach areas inaccessible to ground crews and helping to control the fire's spread from above (Williams & Martin, 2020).

The coordination of these efforts is overseen by a "fire commander," who ensures that both ground and air teams work efficiently and effectively (Taylor, 2019). The fire commander is responsible for strategic decision-making and resource allocation, directing the activities of "ground teams" and "air teams." Together, these teams execute a cohesive firefighting strategy, aiming to contain and extinguish the fire as quickly and safely as possible. The integration of ground and aerial interventions under the fire commander's guidance is crucial for addressing the multifaceted challenges posed by forest fires, ensuring a coordinated and comprehensive suppression effort (Harris & Lee, 2023).

2.5 Aerial firefighting

Aerial firefighting is a critical component of wildfire management, with the selection of appropriate aircraft models playing a pivotal role in the effectiveness and efficiency of aerial firefighting operations.

The practice of combating forest fires aerially can be traced back to the 1929 observations of German pilot Friedrich Karl von Koenig-Warthausen, who reported sighting a fire while soaring over the Santa Lucia Range in California (Turner, 2020).

Aerial firefighting relies on a variety of aircraft to combat wildfires, encompassing both fixed-wing aircraft and helicopters. Fixed-wing aircraft, such as water bombers or tanker planes, are frequently deployed to release substantial amounts of fire retardant or water onto wildfires.

2.5.1 Fixed-wing Aircraft

The Turkish Aeronautical Association initially developed aerial firefighting technology in Türkiye in 1985. Four Dromader fixed-wing aircraft were employed for extinguishing fires, while one Cessna served for reconnaissance and could drop between 800 and 1000 liters of water. Fixed-wing aircraft known as "air tankers" are employed in aerial firefighting missions. When combating wildland fires, they can transport and release water or fire retardant using the tanks that are attached to them. "Air-tanker" is the phrase used in official paperwork, and it primarily refers to fixed-wing aircraft based in the United States (Koc, 2022).

There are various types of air tankers, including:

1. **Single Engine Air-tankers (SEATs):** the smallest type of air-tankers used in aerial firefighting. These aircraft are capable of delivering up to 800 gallons of fire retardant or water to assist wildland firefighters on the ground. Due to their smaller size, SEATs are particularly effective for combating wildfires in lighter fuels such as grasses and sagebrush, where large volumes of retardant or water are not necessary. Their agility and speed allow them to quickly respond to new

fire outbreaks and operate in areas with limited access. An example of a SEAT is the Air Tractor AT-802, which is designed for rapid deployment and efficiency in wildfire suppression (Harris P. , 2021).

2. **Large Air-tankers (LATs):** Often known as "Next Gen" air-tankers, LATs are able to carry 2,000–4,000 gallons of water or fire retardant, which is a larger capacity than SEATs. These aircraft may navigate better in a variety of terrain since they are more maneuverable than the very huge air-tankers. LAT(s) are perfect for bigger, more intense flames because they can provide significant quantities of fire suppressants, which is a vital assistance for wildland firefighters (Morgan, 2020). Modular Airborne Fire Fighting Systems (MAFFS)-equipped P2V, HC-130H, BAe-146, MD-87, and C-130 aircraft are a few examples of LATs. These aircraft are adaptable equipment for managing wildfires because they offer a compromise between capacity and mobility.

3. **Very Large Air-tankers (VLATs):** The biggest type of air-tankers, with the ability to dump thousands of gallons of fire retardant at once. Though they are less maneuverable than smaller air-tankers due to their massive size, VLATs can cover large regions in a single pass. When large-scale suppression efforts are required due to big fire incidents, VLATs are usually deployed. They may ensure extensive coverage by dropping fire retardant from a minimum of 250 feet above the charred area (Williams & Davis, 2018). Two well-known instances of VLATs that are essential to ground firefighting operations are the Boeing 747, which can deliver 17,500 gallons, and the DC-10, which can carry up to 9,400 gallons.

4. **Water Scoopers:** the amphibious vehicles are made to skim the surface of bodies of water and collect water to be dropped from the air onto wildland fires. These aircraft are capable of delivering up to 1,600 gallons of water, which is frequently combined with foam retardants to increase its efficacy in fighting fires. Water Scoopers need water sources that are roughly 6.5 feet deep and 300 feet wide. They can fill their tanks from lakes and rivers in as little as 12 seconds. They can dump water quickly and repeatedly because they can do it from a height of roughly 100 to 150 feet above the earth. The Air Tractor Fire Boss and the

Bombardier CL-415 are two examples. In some Canadian government documents, these aircraft are referred to as "water bombers," particularly those capable of operating from both solid ground and water (Green, 2023).

5. **MAFFS:** If required, military C-130 aircraft can be equipped with the portable MAFFS fire retardant delivery system, allowing for the conversion of the aircraft into air-tankers without requiring significant structural adjustments. During the height of wildfire season, MAFFS units serve as vital surge capacity and are utilized as sizable air-tankers. The MAFFS apparatus and fire retardant are owned by the United States Forest Service ( ), and the C-130 aircraft, flight crews, maintenance staff, and support personnel are provided by the Department of Defense (DOD) for the purpose of combating fires (Thompson, 2019). By working together, we can respond to wildfire emergencies quickly and adaptably, which improves our ability to battle fires overall.

2.5.2 Helicopters

Helicopters, playing a pivotal role in this firefighting approach, demonstrate versatility in transporting and delivering water or fire retardant to effectively address wildfires. These globally deployed helicopters are specifically designed to operate in diverse environments and conditions, supporting firefighting efforts by making precise water drops in challenging locations and transporting firefighting crews to strategic points. The types of helicopters which is also play a crucial role in aerial firefighting, some are called Heli-tanker equipped with a front-mounted foam cannon (Erickson Air Crane) or carry buckets for firefighting and delivering water or fire retardant to combat wildfires (Robinson, 2021).

The cooperation between helicopters and fixed-wing aircraft enhances the overall effectiveness of aerial firefighting efforts. While helicopters focus on precise, targeted drops and supporting ground crews, fixed-wing aircraft lay down broad swaths of fire retardant to create strategic firebreaks (Edwards & Smith, 2022). This combination allows for both immediate tactical responses and longer-term strategic planning. By working in concert, these aircraft can adapt to changing fire conditions, cover more ground, and ensure that resources are deployed where they are needed most.

In essence, the collaboration between helicopters and fixed-wing aircraft constitutes a robust and multifaceted approach to wildfire suppression. This integrated aerial firefighting strategy maximizes the strengths of each type of aircraft, providing a dynamic and responsive means of combating wildfires and protecting vulnerable areas from destruction (Martin & Lee, 2020).

As shown below in the Table 6 The various kinds of firefighting aircraft that are employed worldwide to combat forest fires with their respective country of origin and categories for fixed-wing aircraft, the categories are specified as "Medium," "Heavy," and "Very Heavy," while for helicopters are specified as "Light," "Medium," and "Heavy."

Table 6: Fire Fighter Aircraft Models

Fixed-Wing		
Aircraft Model	**Country of Origin**	**Category**
Canadair CL-215	Canada	Medium
Canadair CL-415	Canada	Medium
Air Tractor "Fire Boss"	United States	Light
Lockheed C-130 Hercules	United States	Medium
Ilyushin Il-76	Russia	Heavy
Boeing 747 Supertanker	United States	Very Heavy
Douglas DC-10	United States	Heavy
DHC-2 Beaver	Canada	Medium
Beriev Be-200	Russia	Medium
BAe 146	United Kingdom	Medium
Grumman S-2 Tracker	United States	Medium
Helicopters		
Aircraft Model	**Country of Origin**	**Category**
Sikorsky/Erickson S-64 Air crane	United States	Heavy
Boeing Vertol 107/234	United States	Medium
Mil Mi-26	Russia	Heavy
Sikorsky S-70 "Fire hawk"	United States	Medium

Source: (Firefighting Aircraft, 2024)

CHAPTER 3

LITERATURE REVIEW

The effective management of forest fires is a critical concern in many regions worldwide, including Türkiye, where the natural landscape is susceptible to wildfires. This literature review provides an overview of existing research including forest firefighting methods and challenges, firefighting aircraft models, aircraft selection criteria, previous studies on aircraft selection, forest firefighting in Türkiye, and challenges and limitations of existing aircraft.

This study aim to conduct research on the selection of the best aircraft models for forest firefighting, with a particular focus on Türkiye which will have a positive impact on tenders, private sector, institutions under the forest management and the protection of valuable natural resources.

The literature has a large number of studies on decision support models for choosing aircraft for fleet planning in forest firefighting organizations or contractor companies. From a methodological perspective, the models in these studies are scrutinized or assessed, MCDM techniques are typically applied, and the alternative aircraft chosen is decided upon by taking into account a range of aircraft criteria.

3.1 Fire Studies

Forest fire research with the information from the GDF emphasizes the importance of accurate records for effective firefighting efforts and risk reduction initiatives. And also aims to examine prominent numerical data related to forest fires worldwide, in Europe, and in Türkiye since 1937 (Erdoğan, Doganay, & Cihan, 2023). The role of fire in five Mediterranean-type climate ecosystems across the globe: Southern Europe and Northern Africa, Central Chile, Cape Province in South Africa, Southern Australia, and California (Keeley el al., 2012).

3.2 Aircraft Selection and Application of Methods

Every decision implies the weighing of several criteria and factors, which can be done consciously and sometimes implicitly. MCDM methods have been employed in research to address the complexity of aircraft studies on selection for forest firefighting. These methods allow for a systematic evaluation of various criteria to make informed decisions. Studies focusing on MCDM in the context of aerial firefighting operations. Several research projects have been conducted on aircraft selection models. Those can be grouped as; passenger aircraft selection models and general aviation aircraft selection models;

1. *Passenger aircraft selection models*: Employing fuzzy TOPSIS and fuzzy MOORA multi-criteria decision-making techniques, the Aircraft Selection Decision Support Model for Fleet Planning of the Low Cost Airlines done by (Güntut & Gökdalay, 2023). The research done by (Yavuz , Huseyin , & Merve , 2007) investigates the topic of "Aircraft Selection Using Analytic Network Process (ANP): Using the crucial decision-making process for choosing aircraft, Turkish Airlines as the biggest airline in Türkiye makes a case for itself. Using Various Data Normalization Techniques and a Multiple Criteria Decision Making Analysis (MCDMA) method, Aircraft Selection (Ardil C. , 2019).
2. General aviation aircraft selection models
    a. *Firefighting aircraft selection model:* In different studies conducted use the AHP method like aircraft selection for aerial firefighting operations (Edvin & Muharem, 2022), Applying Multiple Criteria Group Decision Making Analysis, Aerial Firefighting Aircraft Selection with Standard Fuzzy Sets (FS) (Cemal, 2023),

    b. *Civil and Military Training aircraft selection model:* Research on the choice of trainer aircraft was conducted by (Ardil C. , 2020), who combined the PARIS and TOPSIS approaches with preference analysis with mean weight and entropy weight methods. The Spanish Air Force's selection of military training aircraft is investigated in Additive Ratio Assessment Full Consistency Method

(ARAS-FUCOM) approach (Ha's, Pham , & Yonghoon, 2020) for the Vietnam People's Air Force (VPAF), MCDMA method used by (Ardil, Pashaev, Sadiqov, & Abdulla, 2019) for Selecting and Evaluating Fighter Aircraft, with Fuzzy Logic (FL) (Sánchez-Lozano , Serna, & Dolón-Payán, 2015), The researchers (Ayse , Konstantinos , & Muhammad , 2020) integrated various risk factors analysis with both the AHP and the TOPSIS and the research employs a fuzzy multiple criteria decision-making approach by extending the TOPSIS to a fuzzy environment (Chang, Tien-Chin , & Tsung-Han, 2007).

c. *UAV selection model:* across various industries and applications. (Zhang & Kovacs, 2012) Review different types of UAVs and their applications, highlighting capabilities and limitations. (Colomina & Molina, 2014) Discuss criteria for selecting UAVs in surveying, emphasizing accuracy and data processing capabilities. (Tsouros, Bibi, & Sarigiannidis, 2019) Present a multi-criteria decision-making approach for precision agriculture, considering factors like payload and flight duration. (Siebert & Teizer, 2014) Provide an overview of UAV technology in civil engineering, focusing on construction monitoring and infrastructure inspection. (Javadpour & Moradi, 2020) Propose a hybrid MCDM model for optimizing UAV selection across industries, integrating FL and analytical hierarchy processes. These articles collectively offer valuable guidance for choosing the right UAV based on specific needs, technological requirements, and industry standards.

3.3 Studies Review with the Solution

Overview of existing research conducted as provided below in the table, It summarizes key aspects of each study, including the authors, titles, methods used, evaluation criteria, types of aircraft considered, the main aims of the research, and the best solutions or conclusions drawn. The Table 7 serves as a valuable resource for understanding the diverse approaches and findings by summarizing the Studies of the Aircraft Selection and Evaluation made in the Literature,

Table 7: Studies on Aircraft Selection and Evaluation

S/N	**Author**	**Research Title**	**Methods Used**	**Criteria**	**Best Solution**
1	Cemal Ardil (2023)	Aerial firefighting aircraft selection With standard FS(s) using multiple Criteria group decision making analysis	Fuzzy PMM	Price, Operating expenses per hour, Performance of the aircraft and Aircraft survivability.	For the Air Fire Service, the best aer Firefighting aircraft is selected and r
2	Güntut, C. and Gökdalay, H.M. (2023).	Aircraft selection decision support model For fleet planning of the low cost airlines	Fuzzy TOPSIS and Fuzzy MOORA	Technical (Range, Carrying Capacity, Fuel Efficiency, Auxiliary Equipment Spare Part, Technical Support, Maximum Take-Off Weight (MTOW) and Utilization Period), Economical (Price, Demand, Finance Options, Aircraft Similarity, Cost per Available Seat Mile (CASM) and Internal Rate of Return), Political (Embargo and Foreign Policy), Environmental (Noise and CO2 Emission), Passenger Satisfaction Reliability and In-Flight Entertainment Systems	Among all the aircraft types, it was discovered that the Airbus 321NEO was the most suitable for the low-cost airline business model.

3	Muharem Šabić and Edvin Šimić (2022)	Aircraft selection for aerial Firefighting operations	AHP	Cost of a new or used aircraft, Aircraft performance, Water capacity and operating hourly cost	Based on the performed AHP analysis, the Air Tractor AT-802 fire-fighting aircraft variant F I Fire Boss was selected according to the stated criteria.
4	Cemal Ardil (2019)	Aircraft selection using multiple Criteria decision making analysis Method with different data Normalization techniques	MCDMA Method.	Price of Aircraft, Fuel Efficiency per Seat, Aircraft Range, Aircraft Seat Capacity, Maximum Takeoff Weight and Maximum Payload	This paper offers a novel integrated approach to decision making by taking into account airplanes as well as the many criteria utilities theory and the maximal regret minimization theory techniques. Aspects of technology, finances, and the environment.
5	Pham Van Hoana and Yonghoon Hab (2020)	ARAS-FUCOM approach for VPAF Fighter aircraft selection	ARAS-FUCOM	The aerodynamic characteristic, the maximum takeoff weight, Armament, Avionics, Power engine, Maximum speed, Service ceiling, climbing rate, Combat radius, The acquisition cost The operation cost, Reliability and Strategic cooperation	The finest option at hand is the Su-35.

6	Zhang, C., & Kovacs, J. M. (2012).	A Review of UAV Types and Their Applications	Review and analysis	UAV types, applications, capabilities	Depends on application; varies per industry
7	Colomina, I., & Molina, P. (2014)	Criteria for Selecting the Right UAV for Surveying	Survey and analysis	Accuracy, flight time, data processing	Application-specific; surveying applications
8	Tsouros, D. C., Bibi, S., & Sarigiannidis, P. G. (2019).	Multi-Criteria Decision Making for UAV Selection	MCDM approach	Payload, flight duration, sensor integration	Tailored to precision agriculture
9	Siebert, S., TeizSiebert, S., & Teizer, J. (2014) er, J.	UAV Technology in Civil Engineering: An Overview	Literature review, case studies	Monitoring, inspection, infrastructure	Depends on project; civil engineering use
10	Javadpour, R., & Moradi, M. (2020).	Enhancing UAV Selection through a Hybrid MCDM Model	Hybrid MCDM, FL, AHP	Hybrid MCDM, FL, AHP	Optimization across various industries

11	J.M. Sánchez-Lozano and J. Serna, A. Dolón-Payán (2015)	Evaluating military training aircrafts Through the combination of Multi-criteria decision-making processes with FL. A case study in the Spanish air force academy	The MCDM process was combined with FL. The AHP was used to obtain the weights of the criteria and, through the TOPSIS, the alternatives were evaluated	Service ceiling, Cruising speed, Stalling speed, Endurance, Positive Limit Load Factor, Negative Limit Load Factor, Take-off distance, Landing distance, Human factors, Flying and handling qualities, Security systems and Tactical capability	The Pilatus PC-21 aircraft was determined to be the most suitable option when the decision-making procedure was carried out.
12	Ardil, C., Pashaev, A. M., Sadiqov, R. A., and Abdullayev, P. (2019)	MCDMA for Selecting and evaluating fighter aircraft	Entropy weight method (EWM)	Maximum cruising speed, Service ceiling, Rate of climb, Maximum takeoff weight, Maximum payload, Power, Fuel tank capacity, Fuel economy, Minimum take off distance, and Minimum landing distance.	Sensitivity analysis is done and the fighter aircraft alternatives are ranked according to their final evaluation scores.

13	Yilmaz, A.K., Malagas, K., Jawad, M. and Nikitakos, N. (2020)	Aircraft selection process with TOPSIS and AHP integration	Both AHP and TOPSIS	Strategic criteria, financial criteria, Operational criteria and Maintenance criteria	Criteria and benchmarking results have also shown that training provided by the Cessna 172S Cessna/Reims-Cessna 172/F172 Series should be successful, and that this particular aircraft is simple to identify and has no issues with operation.
14	Cemal Ardil (2020)	Trainer aircraft selection using preference Analysis for reference ideal solution (PARIS).	PARIS, and TOPSIS	Aircraft Maximum Takeoff Weight, Cruise Speed, Aircraft Range Service Ceiling, Rate of Climb and Aircraft Capacity	The most appropriate alternative trainer aircraft was determined to be the King Air C90GTi.

15	Tien-Chin Wang and Tsung-Han Chang (2007)	Application of TOPSIS in evaluating initial training Aircraft under a fuzzy environment	TOPSIS	Fuel capacity, Power plant, Service ceiling, Max. G limits, Min. G limits, Max. Operating speed, Econ cruising speed, Max. Speed with landing gears down, Max. Speed with flaps down, Stalling speed: flameout, Max. Cruising speed, Max. climbing rate at S/L, Take-off distance, Landing distance, Take-off to 50 feet and Landing from 50 to full stop	According to the ranking of the seven first-training aircraft discussed here, KT-1 is the most effective aircraft.
16	Yavuz Ozdemir, Huseyin and Basligil, Merve Karaca (2007)	Aircraft selection using ANP: a case for Turkish airlines	ANP	Cost, Time, and Physical attributes	They convinced them to buy the B737, which was the most practical option.

CHAPTER 4

METHODOLOGY

The methodology involves a systematic evaluation of key performance indicators such as “Technical performance capabilities of the selected firefighting fixed wing aircraft like flight duration, water tank capacity, aerodynamic characteristics, engine power, and refill efficiency alongside Hourly operational costs, including fuel efficiency and maintenance cost. It also considers purpose-built features like amphibious structure and retrofit options.

The methodology, by systematically collecting, analyzing, and interpreting data related to these criteria, ensures that each aircraft model is evaluated comprehensively and consistently. This process involves quantitative measurements as mentioned the specifications of aircraft models such as capacity and cost. Those data are often sourced from technical sheets, operational records, published articles and manufacturer reports. Also, qualitative assessments, incorporating expert opinions through the interview and empirical data to provide a fair and balanced comparison of each model's capabilities and costs.

The majority of the circumstances that decision makers face in their daily lives are very challenging. This sophistication results from the inability to decide because of uncertainty. In numerous scenarios, individuals articulate their views, gratitude, and assessments of worth verbally while engaging in the process of making decisions.

The MCDM approaches, which will be applied in the study, will be thoroughly explained in this chapter. Following the techniques section, the study's methodology will be provided. The objective, criteria, and aircrafts employed in this investigation will also be covered later. These techniques are called MOORA, TOPSIS, and Fuzzy AHP. These techniques were applied to the current study because they greatly aid in the resolution of decision-making issues and the challenge of choosing aircraft models for forest firefighting aircraft in Turkiye, which presents notable benefits.

Nonetheless, the study's selected methodologies have drawn considerable criticism. The chosen approach, known as AHP, enables the resolution of complicated issues and is a reasonable combination of expertise, intuition, and prior knowledge. Moreover, decision-makers have the option to participate in the process in both an objective and subjective manner. Since TOPSIS is a technique that offers a solution that reduces the cost criterion while maximizing the benefit criterion a highly important criterion it has been chosen for this investigation. By normalizing and comparing ratios of criteria values, MOORA is selected due to its robustness in managing various criteria, which allows it to handle both advantageous and non-beneficial criteria with equal effectiveness. This method simplifies the decision-making process by minimizing the complexity of calculations, making it versatile and capable of handling a variety of scenarios with multiple objectives.

By maintaining a structured approach, the methodology helps mitigate biases and allows for objective decision-making based on detailed and rigorous criteria evaluations relatively to each aircraft selected. This ensures that the final recommendation on the aircraft model selection is well-founded, addressing the complex needs and challenges of forest fire fighting effectively.

4.1 MCDM Method Overview

MCDM refers to a set of methods and approaches that systematically assist decision-makers in evaluating complex decisions. It is a formal and structured decision-making approach designed to address intricate problems involving conflicting goals, multiple decision-makers, diverse courses of action, uncertainty, and varying subjective valuations. MCDM methods provide transparency, traceability, and reproducibility in decision-making processes particularly in situations with high stakes, conflicting objectives, and a multitude of potential alternatives. Generally, as shown in the Figure 8 shows the steps involved in MCDM processes (Taherdoost & Madanchian, 2023),

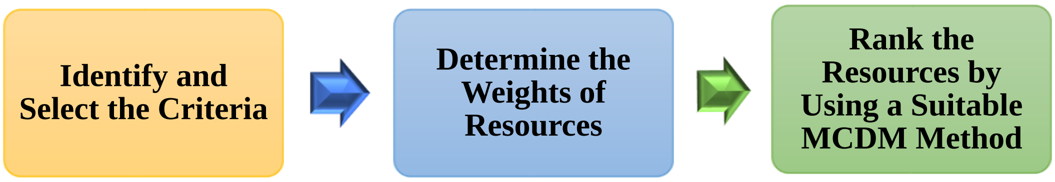

Figure 8: The Main MCDM Steps

The primary aim of MCDM is to determine the optimal solution or alternative that best satisfies a given set of criteria. This involves considering various factors and perspectives in decision-making, offering a comprehensive and rational approach to problems too complex for informal resolution.

MCDM finds applications across various fields, from finance to engineering design. In the specific context provided, MCDM is applied to support decision-makers in systematically evaluating decisions related to aircraft selection. This method proves beneficial in situations where decisions are complex and involve multiple decision-makers, conflicting goals, uncertainty about outcomes, and different subjective valuations. Back 10 years during 2012–2022, the main and top cited MCDM methods with their description based on the results of the conducted search as shown in the Table 8 below (Taherdoost & Madanchian, 2023).

4.2 Weighting Method

A. AHP Method

The AHP is a systematic method to elaborate decision-making, particularly beneficial in resolving problems with several criteria. Developed by Thomas L. Saaty in the 1970s, Saaty and Vargas (Saaty & Vargas, 2012) state that the process of AHP assists in organizing and analyzing decisions by breaking them down into a hierarchy of simpler components, it is comparable to how the human mind handlesa variety of problems. By determining how much one aspect of the problem dominates the other with regard to a particular criterion for which expert opinions are used, it offers a way to define priority values for the criteria involved in decision making (Saaty T. , 2008). AHP is a method particularly effective for decisions with both several tangible and intangible criteria and alternatives, as it captures both the rational and intuitive aspects of decision-making. The following steps are the explanations of procedures applied in the AHP method process,

Table 8: The Main MCDM Methods

Method	Description
AHP	AHP involves systematically comparing criteria in pairs to establish their relative importance within a hierarchical structure.
BWM	Best Worst Method (BWM) identifies the best and worst criteria, conducting pairwise comparisons between them and other criteria for decision analysis.
TOPSIS	TOPSIS ranks alternatives based on their proximity to the ideal solution.
ANP	ANP extends AHP, using a non-linear approach and Markov-chain-based aggregation for decision analysis.
VIKOR	VIKOR is a compensatory method derived from TOPSIS, minimizing the distance to the ideal solution with linear normalization.
FUZZY TOPSIS	Fuzzy TOPSIS applies FL to TOPSIS for decision-making under uncertainty.
MAUT	Multi-Attribute Utility Theory (MAUT) incorporates uncertainty and risk preferences into decision support methods for multi-criteria analysis.
SMART	Simple Multi-Attribute Rating Technique (SMART) weighs criteria based on importance and converts these weights into real numbers for decision analysis.
FUZZY AHP	Fuzzy AHP incorporates FL in the evaluation of alternatives within the AHP framework.
FUZZY ANP	Fuzzy ANP expresses criteria weights in the ANP method using FL for decision-making under uncertainty.

Step 1: Problem definition

This step lays the foundation for a structured and systematic decision-making process, ensuring that all significant aspects of the problem are considered. Initially, defining the problem is paramount. This involves articulating the overall objective or goal of the decision-making process, identifying clearly relevant criteria used to evaluate the alternatives or problems by listing all potential solutions and sub-criteria should be related and have common characteristics under the same main criterion for effective comparison.

The objective should be specific yet comprehensive, and the criteria should be related and comparable. It's also important to consider the scope and context of the decision, taking into account the interests of various stakeholders, as the problem may be specific to an individual, group, or organization, with each having varying perspectives.

According to Saaty (Saaty T. , 1990) the problem's framework needs to have enough information to accurately depict the problem while also taking the problem's environment into consideration.

Step 2: Structured hierarchy

In the second step of the AHP, developing a hierarchical framework is crucial for managing the complexity of a decision problem. This involves decomposing the decision into various levels.

Step 3: In AHP, Pairwise comparisons

The process of decomposition once is successfully done and organization of the elements into a hierarchical structure, Pairwise Comparison Matrices (PCMs) are constructed. Pairwise comparison is essential for evaluating the relative importance of the elements within each level of the hierarchy. Elements that share a common feature are grouped together within the hierarchy.

In the context of creating $n \times n$ comparison matrix a for n criteria regarding the relative importance of criterion $\boldsymbol{i}$ to criterion $\boldsymbol{j}$, the elements of the matrix $\boldsymbol{a}$ exhibit the following relationship:

$$\mathbf{a_{ij}} = 1 \text{ and } \mathbf{a_{ij}} = \frac{1}{\mathrm{a_{ij}}} \tag{1}$$

The decision-maker (DM) compares elements pairwise, assessing how much more important one element is compared to another, with respect to a criterion at the next higher level in the hierarchy.

Step 4: Weight derivation

From these pairwise comparisons, priority values or weights for criteria and sub-criteria are derived, which help in evaluating the alternatives. Here, Each PCM is normalized to make the comparisons more consistent and manageable. This is usually done by dividing each element in the PCM by the sum of its column. Then calculating the Priority Vector (or weight vector) for each criterion or alternative is derived from the normalized PCM.

$$\boldsymbol{\lambda}\mathbf{max} = \frac{1}{n}\left(\frac{Weighted\ Sum\ Value}{Criteria\ Weight}\right) \tag{2}$$

$$\mathbf{A} \cdot \mathbf{w} = \lambda\text{max} \cdot \text{w} \tag{3}$$

Usually, the normalized matrix's values in each row are averaged to achieve this. A collection of numbers representing the relative weights of the criteria or options is the end product. When all of a group of criteria's weights are added together, they equal "1".

Step 5: Consistency check

By performing a crucial process step in this stage called the Consistency Check, which serves as an indicator for how accurate the calculated weights are. However, full consistency of the matrix is not necessary for the results to be trustworthy. Since human judgments can be inconsistent, AHP includes a mechanism to measure and evaluate the consistency of the decision-makers pairwise judgments using a Consistency Ratio (CR). This helps to ensure the validity and reliability of the decision-making process.

The Consistency Index (CI) is calculated first in the procedure, which is derived from the maximum eigenvalue $\lambda_{\max}$ of the pairwise comparison matrix.

The CI is calculated using the formula:

$$\boldsymbol{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

In this case, "n" denotes the size of the matrix, or the number of entries being compared.

Using the same scale as the pairwise comparisons, randomly generated reciprocal matrices are used to create the Random Index (RI). It values are averages of the consistency indices of these randomly generated matrices and vary based on the size of the matrix as shown in the Table 9,

Table 9: The RI Values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

The CR is then calculated using the CI and the appropriate RI value:

$$\mathbf{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{5}$$

A “CR” of % 10 or less is generally considered acceptable (Saaty L. , 1983), indicating that the matrix is sufficiently consistent. In other words, the decision-maker's judgments can be considered coherent and reliable. A CR greater than % 10 suggests a problematic level of inconsistency in the judgments. In such cases, it is advisable to review and revise the pairwise comparisons to reduce inconsistencies.

Table 10 (Saaty L. , 1983) Outlines the range of CR for the AHP and their typical interpretations,

Table 10: The Range of CR

Consistency Ratio (CR) %	**Interpretation**
CR = 0	Perfect consistency
0 < CR ≤ 10	Acceptable consistency
CR > 10	Unacceptable inconsistency, review needed

A CR up to % 10 is generally acceptable, suggesting that the judgments are consistent enough for reliable decision-making. A CR above % 10, however, suggests a level of inconsistency that might distort decision outcomes, indicating the need for reassessment of the pairwise comparisons.

Step 6: Calculating global weights

The derivation of global weights in the AHP is a crucial step that combines the local weights of criteria and sub-criteria to determine the overall or global importance of each alternative in the decision-making process. This process essentially synthesizes the information from various levels of the hierarchy to arrive at a final decision. The weights obtained from the pairwise comparisons are used to rank the alternatives, aiding in the decision-making process. In addition, they ensure that the evaluation of alternatives is not only rigorous and methodical but also aligned with the strategic priorities and values of the decision-makers, enhancing the overall effectiveness and relevance of the MCDM process.

4.3 Evaluation Methods

A. TOPSIS Method

TOPSIS is a multi-criteria decision-making method developed by Ching-Lai Hwang and Yoon in 1981. This method evaluates a set of alternatives against multiple, often conflicting criteria, by determining their relative closeness to the ideal solution. In TOPSIS, the ideal solution is the best possible outcome for each criterion (Positive Ideal Solution, PIS), and the worst possible outcome (Negative Ideal Solution, NIS).

Alternatives are then ranked based on their proximity to the PIS and their distance from the NIS. The preferred choice is the one closest to the PIS and farthest from the NIS. TOPSIS is favored for its logical approach, ease of use, and effectiveness in providing a comprehensive decision-making framework.

The TOPSIS method, as outlined by Hwang & Yoon (1981) and further elaborated by (Triantaphyllou, 2000), involves a series of mathematical steps to rank alternatives based on their similarity to the ideal solution. Here is an explanation of the procedure along with the relevant formulas:

***Steps 1. Normalization of the Decision Matrix*:**

In this step involves normalizing the decision matrix to transform the various dimensions of criteria into non-dimensional criteria, which allows for comparisons across different scales.

The decision matrix “**D**” of size “**a”** (alternatives) × “**C”** (criteria) is normalized to form a matrix “$\boldsymbol{r_{ij}}$”, where each element `$\boldsymbol{r_{ij}}$` is calculated using

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{X_{ij}}}{\sqrt{\sum_{j=1}^{n} \boldsymbol{X_{ij}}^2}} \tag{6}$$

***Step 2. Weighted Normalized Decision Matrix*:**

Weights reflecting the importance of each criterion are assigned and then used to multiply the normalized decision matrix. A weighted normalized decision matrix “$\mathbf{V_{ij}}$” is formed by multiplying each element of “$\boldsymbol{r_{ij}}$” with its associated weight `$\boldsymbol{W_j}$`:

$$\boldsymbol{V_{ij}} = r_{ij} \times W_j \tag{7}$$

***Step 3. Determination of the Positive and Negative Ideal Solutions*:**

The Positive and Negative Ideal Solutions also known as the ideal best and ideal worst value. The PIS is defined as the solution that maximizes benefit criteria and minimizes cost or non-beneficial criteria. In contrast, the NIS aims to do the opposite, minimizing the benefit criteria and maximizing the cost criteria.

The PIS is composed of the best values achievable for each criterion where the high value is desired, while the NIS consists of the worst where the low value is desired and the PIS ($\boldsymbol{A^+}$) and NIS ($\boldsymbol{A^-}$) are identified as follows,

- $\boldsymbol{A^+}$ Is the best value: Max for benefit criteria (BC), Min for non-beneficial criteria (CBC) or cost.

$$\widetilde{A}_j^{+} = \left\{ \mathbf{max}\, v_{ij} \ \middle|\ j \in J_{benefit} ; \mathbf{min}\, v_{ij} \ \middle|\ j \in J_{cost} \right\} \quad (8)$$

- A^{-} Is the worst value: Min for benefit criteria (BC), Max for non-beneficial criteria (CBC) or cost.

$$\widetilde{A}_j^{-} = \left\{ \mathbf{min}\, v_{ij} \ \middle|\ j \in J_{benefit} ; \mathbf{max}\, v_{ij} \ \middle|\ j \in J_{cost} \right\} \quad (9)$$

Step 4. Calculation of the Separation Measures

The distance of each alternative to the PIS S_i^{+} and NIS S_i^{-} is calculated, typically using Euclidean distance.

- Euclidean distance from the ideal best formula:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - A_i^{+}\right)^2} \quad (10)$$

- Euclidean distance from the ideal worst formula:

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - A_i^{-}\right)^2} \quad (11)$$

Step 5. The Relative Closeness to the Ideal Solution

The relative closeness of each alternative to the Positive Ideal Solution (PIS) is determined. This matrix, known as the performance of each alternative relative to the PIS or Performance Score "P_i".

$$P_i = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \quad (12)$$

Step 6. Ranking of the Alternatives

Finally, alternatives are ranked according to their relative closeness to the PIS. The alternative with the highest relative closeness will be the best option based performance Score result indicating it is the most preferred option, followed by the next highest, and so forth.

B. MOORA Method

The MOORA method is another robust MCDM technique used for selecting the best alternative among several competing options based on multiple criteria. The process involves several structured steps, each contributing to the systematic evaluation and comparison of the alternatives.

Here's an outline of the procedures typically applied in the MOORA method:

Step 1: Construct the Decision Matrix

Create a decision matrix consisting of alternatives (rows) and criteria (columns). Each cell in the matrix represents the performance of an alternative concerning a specific criterion.

Step 2: Normalize the Decision Matrix

Normalization is essential to make the criterion values dimensionless and comparable. In MOORA, normalization is often done using the ratio system, where each element of the decision matrix is divided by the square root of the sum of the squares for each criterion:

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{X_{ij}}}{\sqrt{\sum_{j=1}^{n} \boldsymbol{X_{ij}}^2}} \tag{13}$$

Where "$\boldsymbol{X_{ij}}$ "is the original value, and "n" is the total number of alternatives.

Step 3: Weight the Normalized Matrix

In MOORA weighting the normalization matrix is done, when weights are assigned to the criteria reflecting their relative importance, and the normalized values are multiplied by these weights as the referring to the equation (7),

$$\boldsymbol{V_{ij}} = r_{ij} \times W_j \tag{14}$$

Where "$\boldsymbol{W_{ij}}$ "is the weight of the ***"j-th*** criterion"

Step 4: Apply the Ratio System

Compute a performance score for each alternative by summing the normalized values for beneficial criteria and subtracting the normalized values for non-beneficial (cost) criteria:

$$\boldsymbol{Y_i} = \sum\nolimits_{j \in J_{benefit}} X_{ij} - \sum\nolimits_{j \in J_{cost}} X_{ij} \tag{15}$$

Where "$\boldsymbol{Y_i}$" is the performance score for the ***"i-th*** alternative"

Step 5: Reference Point Assessment (Optional Variant)

Another variant of MOORA, known as the Reference Point Approach, involves assessing each alternative against a reference point, which is typically the set of the best values observed for each criterion across all alternatives.

Step 6: Rank the Alternatives

Rank the alternatives based on the computed scores from either the ratio system or the reference point assessment. The alternative with the highest score is considered the best.

Step 7: Selection of the Best Alternative

The alternative that ranks highest, having the highest performance score or being closest to the reference point depending on the applied variant, is selected as the best choice.

4.4 Application of Fuzzy Concepts in MCDM

The fuzzy concepts improve the handling of data imprecision and ambiguity, enriching the decision frameworks to be more nuanced and robust. This enables MCDM methods to provide more dynamic, flexible, and realistic solutions across various fields. The application of fuzzy concepts significantly strengthens the methodology, ensuring that the process is scientifically rigorous while also being realistically aligned with operational realities. Consequently, decisions made are not only theoretically sound but also practical and effective in real-world scenarios, making the decision frameworks better suited to address the complex realities of practical decision environments (Klir & Yuan, 1995).

The integration of fuzzy concepts into MCDM significantly enhances the decision-making process, especially in complex and uncertain environments (Kahraman, 2008). Here's an exploration of how FL, FS, and Fuzzy numbers (FN) each play a critical role in enhancing MCDM methods,

A. Fuzzy logic

FL plays an instrumental role in MCDM by facilitating the handling of uncertainties and ambiguities inherent in human decision-making processes. Unlike traditional binary logic, which restricts outcomes to either true or false, FL introduces degrees of truth as a standard mathematical range between 0 and 1. This flexibility allows decision-makers to use natural language terms and subjective judgments effectively when assessing criteria and alternatives.

For instance, terms like "highly important" or "moderately effective" can be quantified using FL, providing a way to input human-like reasoning into the decision model. This capability is invaluable in MCDM as it leads to more adaptive and realistic decision-making frameworks that can accommodate the nuanced preferences and expertise of different stakeholders, thereby making the decision process more inclusive and precise.

B. Fuzzy sets

FS(s) extend the concept of classical sets by incorporating the idea of partial membership, which is defined by membership functions assigning a degree of belonging to each element. This characteristic is particularly useful in MCDM, where decision variables often cannot be precisely defined or measured. For example, criteria such as "sustainability" or "feasibility" may vary in interpretation and importance among experts. FS(s) allow these criteria to be modeled as functions with varying degrees of truth, rather than as binary variables, enabling a more accurate representation of real-world complexity. By applying FS(s), MCDM methods can effectively handle the vagueness and subjective interpretation often seen in real-world data, thus enhancing the robustness and flexibility of decision models.

C. Fuzzy numbers

FN are a special type of FS used primarily to handle the imprecision associated with numerical data, which is common in decision-making scenarios. In MCDM, FN can be used to represent uncertain or imprecise data, such as estimated costs, expected benefits, or risk levels associated with different alternatives. These numbers allow for the modeling of such data in a way that reflects their inherent uncertainty, rather than forcing a precise but potentially inaccurate representation. The use of FN(s) in MCDM facilitates more accurate and meaningful analysis of alternatives under uncertainty, enabling decision-makers to conduct assessments that reflect realistic scenarios and potential variability in outcomes.

By using both the FN and Saaty's Fundamental Scale. As proposed by Saaty (Saaty T. , 1990), a scale of 1 to 5 is used for these comparisons as shown in the Table 11. Each number corresponds to a specific degree of importance, with verbal definitions provided for each value,

Table 11: The Importance Degree

Level of Significance	Definition	FN	Inverse TFN
1	Equal importance	(1;1;1)	(1;1;1)
2	Moderate importance	(1;3;5)	(1/5;1/3;1)
3	Strong importance	(3;5;7)	(1/7;1/5;1/3)
4	Very strong importance	(5;7;9)	(1/9;1/7;1/5)
5	Extreme importance	(7;9;9)	(1/9;1/9;1/7)

Source: (Atik & Yıldız , 2023)

When making comparisons, the DM assigns a value from this scale to each pair of elements, indicating their relative importance. It’s crucial that DMs provide justification for their chosen values to ensure meaningful and justified comparisons.

That means, DMs should avoid assigning importance values without proper justification (Saaty, 1988). The rationale behind each assigned value is vital for the integrity and validity of the AHP process. Actually, the number of criteria used in the decision-making process is reflected in the length of the pairwise matrix.

According to the Chang's method and application, verbal comparisons between criteria are expressed using fuzzy triangular numbers (TFNs). These TFNs illustrate how uncertainty and imprecision can be modeled using three parameters: the lower limit (l), the most likely value (m), and the upper limit (u). Each TFN provides a range within which the true value is expected to lie, with the peak representing the most probable value.

This approach is useful in various decision-making processes where exact values are difficult to determine as shown in the Table 12 of the linguistic variables corresponding to Fuzzy Triangular Number also shown in the Figure 9, (Chen, 2001) and the membership function of a triangular FN (l; m; u) is depicted in Figure 10. The membership Function $P_n(X)$ is defined as,

$$P_n(X) = \begin{cases} 0, & x < l, \\ \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{x-u}{m-u} & m \leq x \leq u \\ 0, \ x > u & \end{cases} \tag{16}$$

Table 12: The Alternatives Evaluation Variables

Numbers	**Linguistic Variable**	**Fuzzy Triangular Number (TFN)**
1	Very Low (VL)	(0; 1; 2)
2	Low (L)	(2; 3; 4)
3	Medium (M)	(4; 5; 6)
4	High (H)	(6; 7; 8)
5	Very High (VH)	(8; 9; 10)

Source: A fuzzy approach to select the location of the distribution center FS(s) and Systems 118 (2001) www.elsevier.com/locate/fss

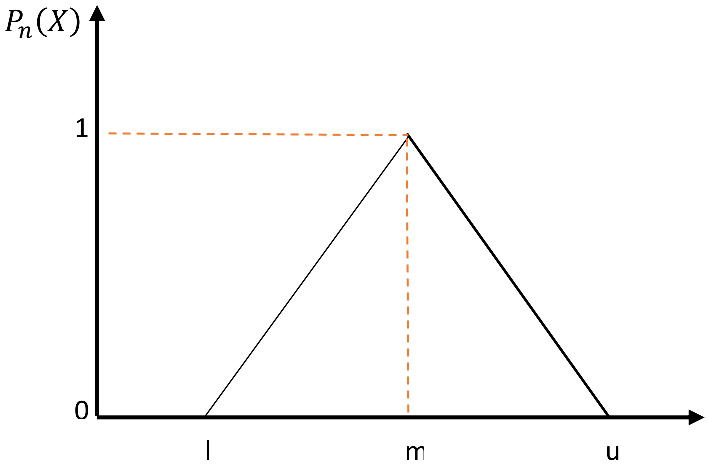

Figure 9: Triangular Fuzzy Number (l, m, u)

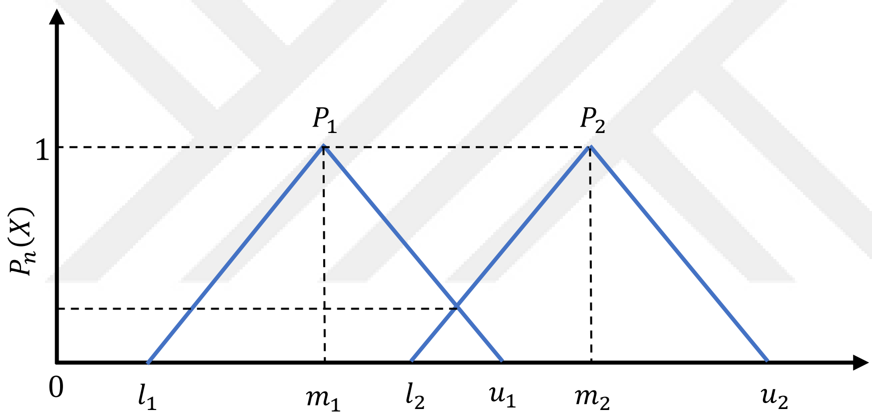

Figure 10: The Membership Function

CHAPTER 5

MCDM APPROACH FOR THE BEST AIRCRAFT MODEL SELECTION FOR FOREST FIREFIGHTING IN TÜRKİYE

5.1 Aim of the Study

The aim of this study is the selection of the best aircraft models, which is fundamental to enhancing the efficiency and effectiveness of forest firefighting operations and improving overall wildfire management in Türkiye. It forms the basis for recommendations and decision-making, which can have a direct and substantial impact on tenders by guiding them towards acquiring the most effective and efficient firefighting aircraft, enhances response capabilities, optimizes budget allocation, minimizes environmental impact, and contributes to long-term conservation efforts and the protection of valuable natural resources

5.2 Importance of the Study

The importance of this topic lies in its potential to improve wildfire management in Türkiye faces the constant threat of wildfires particularly during dry seasons, enhance safety, and protect natural resources, not only in Türkiye but also in similar regions globally. Selecting the best aircraft models can significantly offering valuable insights for policy decisions, academic knowledge, and international collaboration in the field of aerial forest firefighting. Also, enhance the country's capacity to combat and mitigate wildfires.

5.3 Case Study: Türkiye

a) Geographical Overview

Türkiye, located at the crossroads of Europe and Asia, has a diverse and rich geographical landscape. Its varied topography includes mountain ranges, plateaus, and extensive coastal areas along the Aegean, Mediterranean, and Black Seas. This geographical diversity supports a wide range of ecosystems and natural habitats, contributing to Türkiye's rich biodiversity and unique environmental features (Kaya & Demir, 2022).

b) Forests in Türkiye

Forests cover approximately % 26 of Türkiye's land area, amounting to around 20.749 million hectares out of a total landmass of 77.079 million hectares. These forests are primarily located in the northern regions along the Black Sea coast, the western regions near the Aegean Sea, and the southern regions along the Mediterranean coast. Türkiye's forests are diverse, consisting of coniferous, deciduous, and mixed forests. Key species include Turkish pine (Pinus brutia), Scots pine (Pinus sylvestris), oak, and beech, these key tree species play vital roles in Türkiye's forest ecosystems. Their varying degrees of fire resilience and recovery capacity highlight the need for tailored forest management strategies to protect and sustain these forests amidst increasing wildfire risks (Yilmaz & Koc, 2021).

- Turkish Pine (Pinus brutia): also known as Calabrian Pine, is a dominant species in southern and western Türkiye. Adapted to the Mediterranean climate, it thrives at altitudes up to 1200 meters. This species is crucial for preventing soil erosion and maintaining ecological balance. Turkish Pine is highly fire-adapted, with thick bark and the ability to regenerate from seeds released after a fire. Despite its resilience, frequent and intense wildfires can still pose a threat to these ecosystems.

- Scots Pine (Pinus sylvestris) is predominantly found in northern Türkiye, particularly along the Black Sea coast, thriving in cooler, more humid climates.

Growing up to 40 meters tall, Scots Pine has moderate fire resistance due to its thick bark and high canopy. However, it is less fire-adapted compared to Turkish Pine. Frequent or high-intensity fires can significantly damage Scots Pine forests, affecting their ability to regenerate.

- Oak (Quercus spp.) are widespread across Türkiye, especially in deciduous and mixed forests. They can grow up to 30 meters tall and are essential for maintaining biodiversity. Oaks have thick, rough bark and can resprout after fires, making them relatively resilient. However, intense and frequent fires can still harm oak forests, potentially reducing their capacity to support diverse ecosystems.

Beech (Fagus spp.) are primarily found in northern and western Türkiye, preferring cooler, moist regions. Growing to heights of 25-35 meters, beech trees have smooth, gray bark and are less fire-adapted compared to pine species. Beech forests contribute significantly to soil fertility and forest structure but are particularly vulnerable to the increasing frequency and intensity of fires due to climate change, which can severely affect their ability to reduce overall forest resilience. In Figure 11, the forest Assets of Türkiye can be seen.

c) Forest Fires in Türkiye

Forest fires are a significant environmental issue in Türkiye, particularly during the hot, dry summer months. Approximately 12 million hectares of forested land are under constant threat of forest fires. The Mediterranean climate in the southern and western regions, characterized by hot, dry summers and mild, wet winters, creates ideal conditions for wildfires. Factors contributing to forest fires include:

- Climate Conditions: High temperatures and prolonged droughts increase the risk of wildfires.
- Human Activities: Agricultural practices, illegal logging, and accidental fires caused by negligence are common causes.
- Topography: Steep slopes and rugged terrain can make firefighting efforts challenging, complicating the containment and control of fires.

➢ Forest fire management in Türkiye is carried out by state forest enterprises operating under regional directorates, generally under the responsibility of the Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks. Given the geographical and climatic similarities with other Mediterranean countries, forest fires become a critical concern during the summer period (Ozdemir & Yilmaz, 2023).

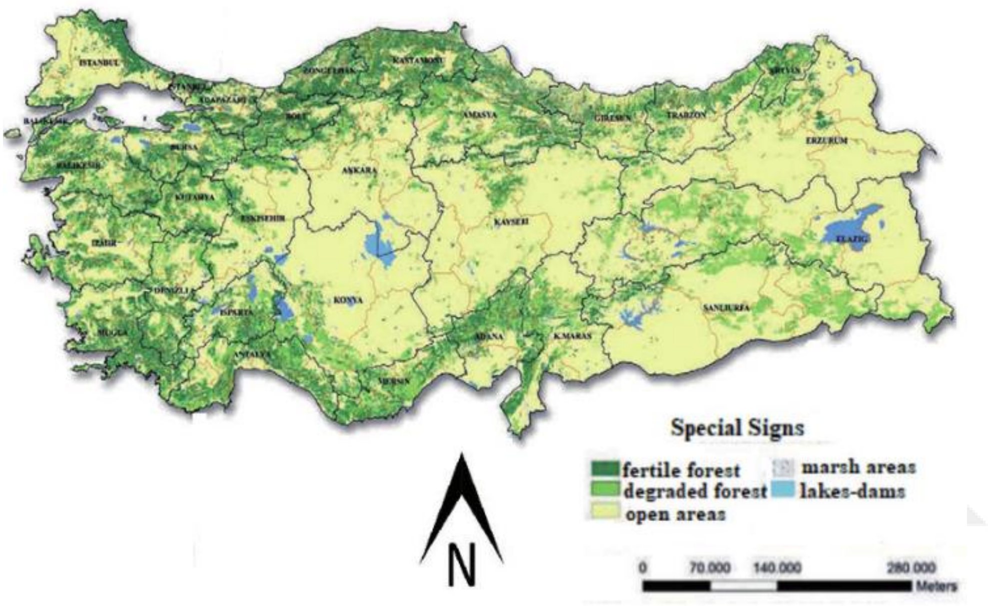

Figure 11: Türkiye's Forest Assets.

Source: (Sarikoc, 2020)

d) Sea and Coastal Areas

Türkiye has a vast coastline stretching over 8.000 kilometers along the Aegean, Mediterranean, and Black Seas. These coastal areas are vital for the country's economy, supporting tourism, fishing, and maritime trade. The Aegean and Mediterranean coasts are particularly popular tourist destinations, known for their beautiful beaches, historical sites, and favorable climate. Coastal ecosystems, including wetlands, dunes, and estuaries, are rich in biodiversity and provide critical habitats for numerous species.

e) Climate Change

Climate change poses a significant threat to Türkiye's natural environment, economy, and public health (Aksoy & Yildiz, 2023). The country is experiencing,

- Rising Temperatures: Average temperatures have increased, leading to more frequent and severe heatwaves.
- Changing Precipitation Patterns: Altered rainfall patterns contribute to prolonged droughts and increased flood risks.
- Sea-Level Rise: Rising sea levels threaten coastal areas, leading to erosion and loss of habitats.
- Increased Wildfire Risk: Higher temperatures and prolonged dry periods increase the likelihood and intensity of forest fires.

In the forested region, Turkish Red Pine is the most sensitive and abundant tree species, accounting for % 46,83 of the total. Türkiye's forest fires are highly observable due to the dominating red-pine tree species, relative humidity, wind direction, and speed. Generally speaking, fire sensitivity is greater in the west and south of the nation, as indicated by the colors in the Figure 12 below,

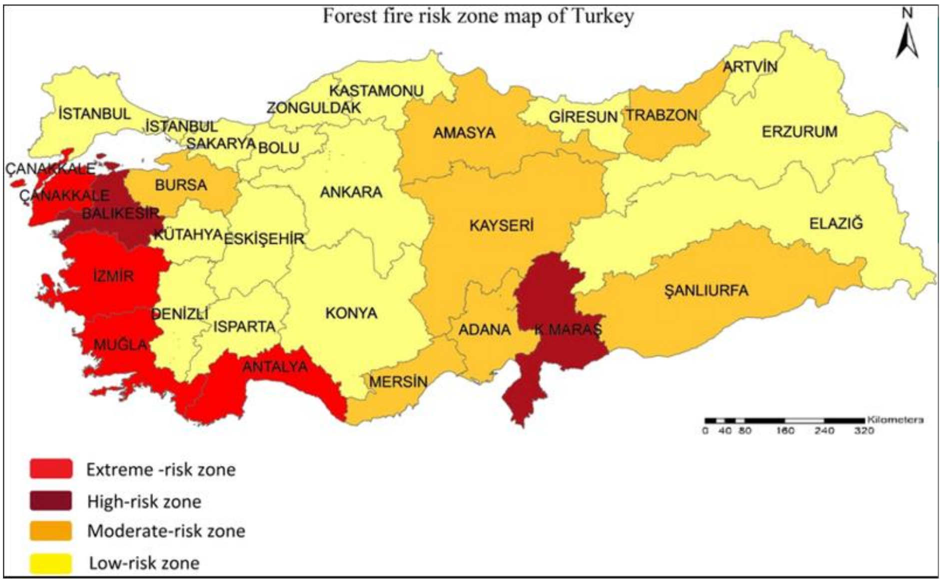

Figure 12: Türkiye’s Forest Fire Risk Zone Map

Source: (Sevinc, 2022)

f) Impact on Forests and Biodiversity

Climate change impacts Türkiye's forests and biodiversity. Changes in temperature and precipitation affect the health and distribution of forest species, making them more susceptible to pests, diseases, and wildfires. Loss of biodiversity and habitat degradation are significant concerns. Pine forests, particularly those dominated by Turkish pine, are at increased risk of fire and pest outbreaks, which can lead to substantial ecological and economic losses.

g) Mitigation and Adaptation Efforts

Türkiye is taking steps to address the challenges posed by climate change through mitigation and adaptation strategies:

- Afforestation and Reforestation: Increasing forest cover to enhance carbon sequestration and reduce wildfire risk. These efforts are crucial in rehabilitating degraded lands and restoring natural habitats.
- Improved Fire Management: Enhancing early warning systems, firefighting capabilities, and community awareness to prevent and manage forest fires. This includes investing in firefighting technology and training for rapid response.
- Sustainable Land Use: Promoting sustainable agricultural and forestry practices to reduce environmental impact. Practices such as agroforestry and sustainable grazing can help maintain soil health and biodiversity.
- Coastal Protection: Implementing measures to protect coastal areas from erosion and sea-level rise. Coastal defense structures, habitat restoration, and integrated coastal zone management are part of these efforts.

Türkiye's diverse geographical conditions, including its forests, coastal areas, and susceptibility to climate change, present both opportunities and challenges. Effective management and adaptation strategies are crucial to protecting the country's natural resources and ensuring sustainable development. Through comprehensive policies and community engagement, Türkiye can enhance its resilience to climate change and safeguard its rich natural heritage for future generations (Demir & Kara, 2023).

5.4 Model of the Study

The selection process for identifying the best aircraft model for forest fire fighting involves three main stages. Firstly, the criteria for the model are identified. Secondly, the criteria weights are determined using Fuzzy AHP computations.

Lastly, the final ranking of the aircraft models is performed using Fuzzy TOPSIS, with the results validated through the MOORA method.

The Fuzzy AHP- Fuzzy TOPSIS and MOORA model is chosen for this research due to three key reasons: its straightforward mathematical and computational processes, its ability to rank alternative locations based on overall performance, and its hierarchical framework that simplifies information input and focuses on specific areas of the larger problem.

Figure 13 shows the integrated structure approach with both expert insights and robust MCDM techniques to effectively select the most suitable aircraft, ensuring decisions are well-founded and thoroughly validated,

This structured approach will not only clarify the relationships and comparability between different elements of the decision problem but also provides a clear overview, thereby setting the stage for the systematic and logical decision-making process inherent in AHP, TOPSIS and MOORA. The set of 3 Main criteria and 7 Sub-Criteria in this study have taken into consideration as shown in the Table 13 and Figure 14 below,

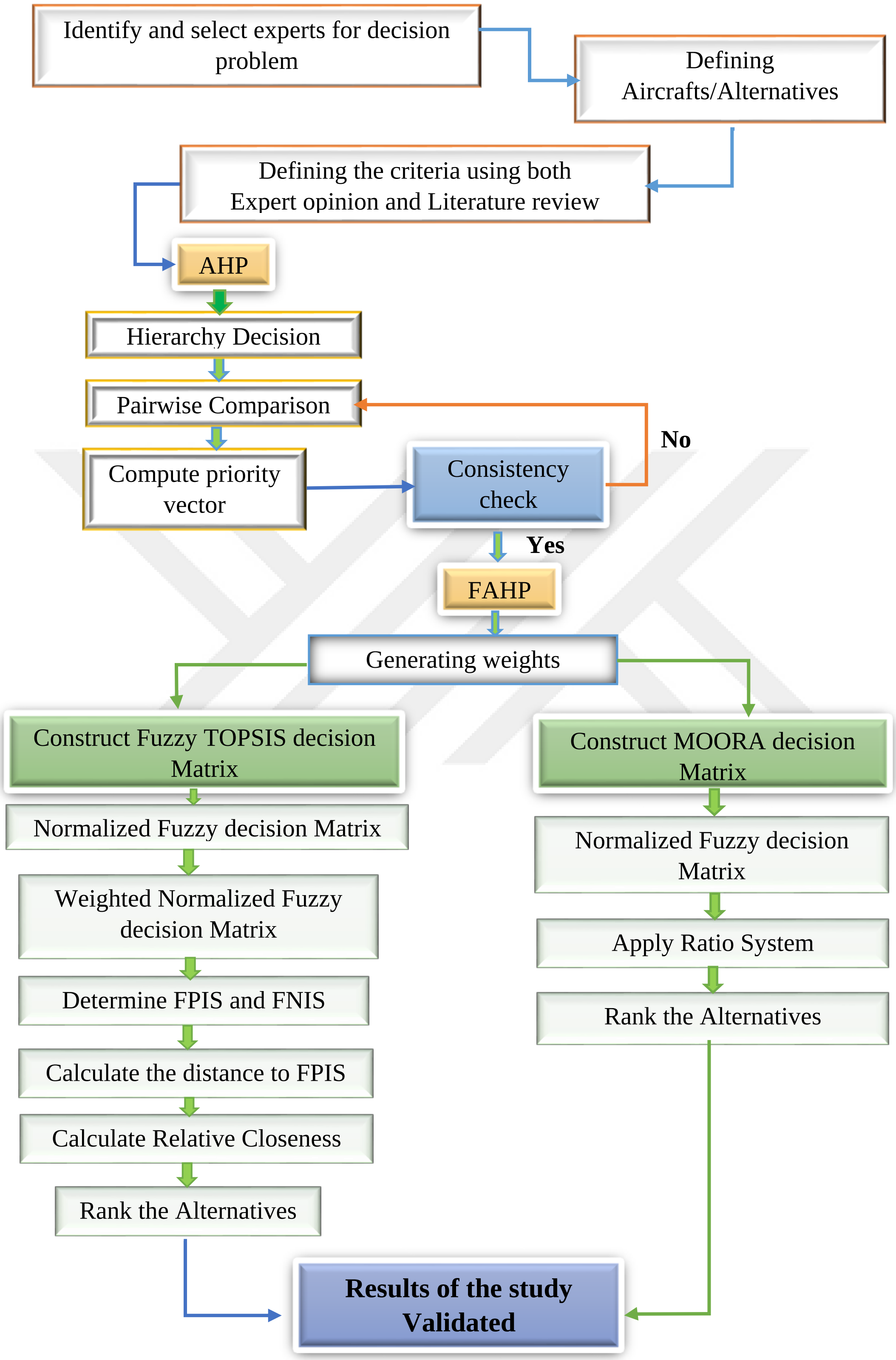

Figure 13: Evaluation Process

The model clarifies the relationships and comparability between different elements of the decision problem. Provides a clear overview, thereby setting the stage for the systematic and logical decision-making process.

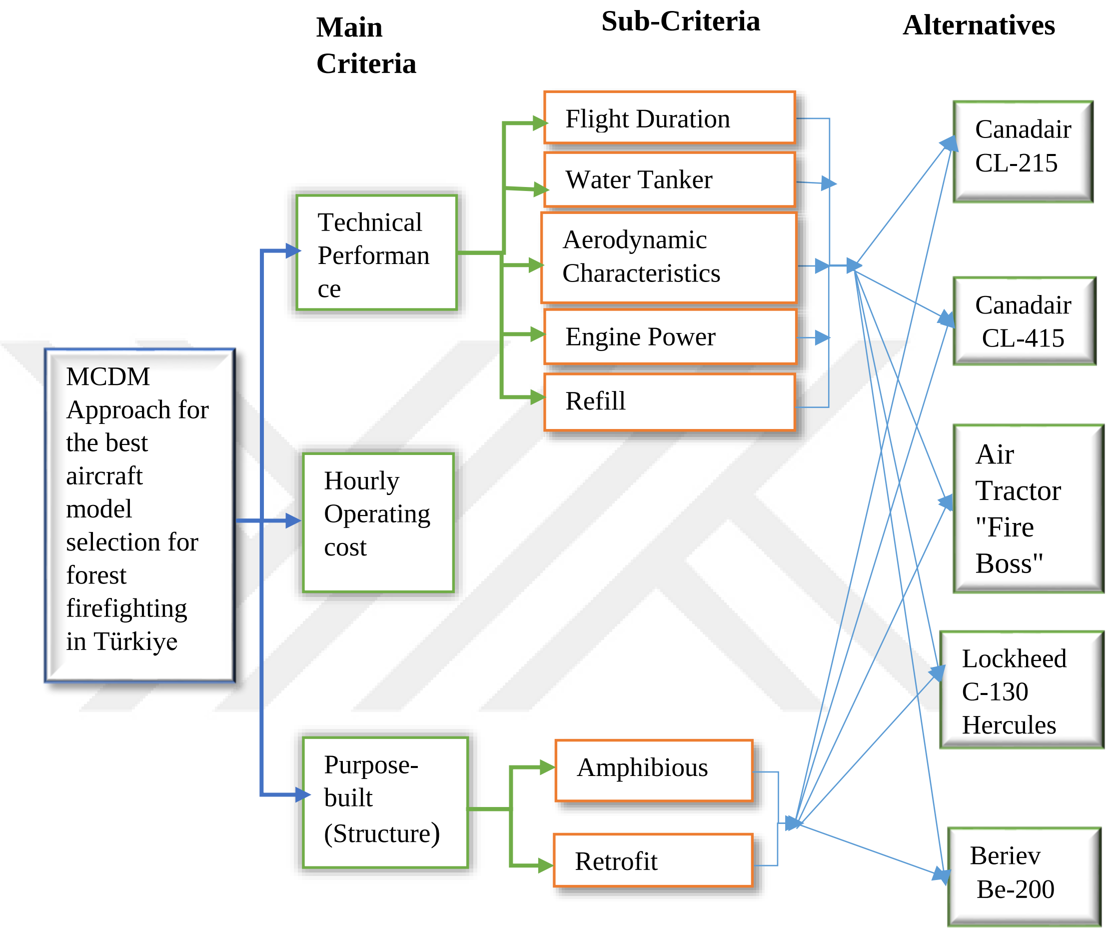

Figure 14: Model of Study

A. Criteria

The choice of aircraft for any forest firefighting mission or operation depends on several factors like aircraft specifications or characteristics and location of the fire, terrain, budget, and the resources available. For example, larger fires in remote areas might require the use of heavy air tankers, while smaller fires near urban areas might be addressed with smaller aircraft. Additionally, many firefighting agencies use a combination of aircraft to tackle wildfires effectively.

Table 13: The Criteria Descriptions

Main Criteria	Sub Criteria	Explanation
C_1		**Technical Performance**
	C_{11}	**Flight Duration:** known as "airtime" refers to the period during which an aircraft remains airborne from the moment it takes off until the moment it lands. This duration is typically measured in hours, minutes, and seconds.
	C_{12}	**Water Tank capacity**: Carry water or fire retardant for effective firefighting.
	C_{13}	**Aerodynamic Characteristics (Tactical Capability):** Influences **maneuverability** which gives the Ability to operate in diverse scenarios and environments, low-altitude and slow-speed capabilities which impact wildfire suppression effectively.
	C_{14}	**Engine Power:** Propulsive force generation and efficiency. **Turboprops** with their STOL capabilities, fuel efficiency at lower speeds, and better maneuverability in Hilly terrain (rugged terrain), which is conducive to precision in firefighting operations. **Turbofans** with their high speed, which is beneficial for covering large distances quickly, heavy lift capabilities which is able aircraft to carry massive amounts of water/retardant.
	C_{15}	**Refill**: Capability of making "scoops" in water quickly (Time). Or Turnaround Time: The quickness in refueling and reloading to return to fire zones.
C_2		**Hourly Operating cost**
		Includes the Fuel Cost Efficiency: Cost related to fuel consumption during operations or missions, **Maintenance Cos**t: Includes spare parts used during the maintenance and **Labor cost.**
C_3		**Purpose-built (Structure)**
	C_{31}	**Amphibious**: Aircraft type skimming over a water surface or water floats which means take off/landing on both water and land specifically manufactured for firefighting.
	C_{32}	**Retrofit**: Converted for firefighting purposes and use Land while taking off/Landing.

As shown Table 14 Illustrate the source of the factors considered in the model,

Table 14: The Model Source of Criteria

S/N	AUTHOR	MAIN CRITERIA	CRITERION
1	DECISION MAKERS BY INTERVIEW. MUHAREM ŠABIĆ AND EDVIN ŠIMIĆ (2022) AND CEMAL ARDIL (2023);	**C_1:** TECHNICAL PERFORMANCE	**C_{11}:** FLIGHT DURATION **C_{12}:** WATER TANK CAPACITY **C_{13}:** AERODYNAMIC CHARACTERISTIC **C_{14}:** ENGINE POWER **C_{15}:** REFILL
2	FIRE BOSS AERIAL FIREFIGHTING SOLUTION AND INTERNET SOURCE: HTTPS://FIREBOSSLLC.COM/COST-COMPARISON/	**C_2:** HOURLY OPERATING COST	
3	DECISION MAKERS BY INTERVIEW	**C_3:** PURPOSE-BUILT (STRUCTURE)	**C_{31}:** AMPHIBIOUS **C_{32}:** RETROFIT

B. Alternatives

In this section, the alternatives involved in the case study are analyzed briefly. Forest Firefighting in Türkiye faces a substantial challenge in managing forest fires due to its diverse landscapes and varying climate conditions. It’s important to note that firefighting aircraft are typically operated by government agencies, private contractors, or a combination of both, depending on the region. The selection of the best aircraft model for a particular firefighting operation is made based on a careful assessment of the unique circumstances of that fire. The country has developed strategies for aerial firefighting, involving a fleet of aircraft models. However, there is room for improvement in optimizing the selection of these models based on the unique characteristics of Turkish forests and fire incidents according to firefighting aircraft.

Aerial Firefighting systems are classified in various types of firefighting aircraft exist, including fixed-wing aircraft like water bombers or air tankers and helicopters equipped with water buckets or tanks. Each type has its advantages and limitations, making it crucial to select the appropriate model based on the specific requirements of a region and the type of fire.

Aircraft selection decisions are complex decision types that often require MCDM approaches where the most appropriate aircraft type should be selected according to their abilities by the decision-makers considering available options in making informed and transparent choices in such complex decision environments.

To define the most appropriate aircraft to be evaluated according to the case study, the expert opinions decide five (5) Aircrafts/Alternatives to be evaluated which are Canadair CL-215, Canadair CL-415, Air Tractor "Fire Boss", Lockheed C-130 Hercules and Beriev Be-200. The suitable forest fire combat aircraft selection model for Türkiye's forests and land conditions comparing with the world aircrafts using at forest fires fighting as shown in the Table 15 below listing firefighting aircraft or alternatives in this study taken into consideration used by Spain, Italy, Greece, Russia, Canada, and Belarus based on the most preferred aircrafts in Türkiye for aerial firefighting,

Table 15: The Aircraft in the Model

Fixed-Wing Aircraft			
S/N	**Aircraft Model**	**Category**	**Countries**
1	Canadair CL-215	Medium: Aerial firefighting, search and rescue, cargo transport	Türkiye, Spain, Canada
2	Canadair CL-415	Medium: Aerial firefighting, search and rescue, patrol	Türkiye, Spain, Italy, Greece, Canada
3	Air Tractor "Fire Boss"	Light: Rapid, repeated attacks on wildfires, initial stages	Türkiye, Canada
4	Lockheed C-130 Hercules	Medium: Aerial firefighting, rapid response in remote areas	Türkiye, Canada
5	Beriev Be-200	Medium: Aerial firefighting in diverse environments	Italy, Greece, Russia

1. Canadair CL-215 and CL-415 (Bombardier 215 and Viking 415)

The Canadair CL-215 and CL-415 on the Figure 15, also known as Bombardier 215 and Viking 415 respectively, are a series of amphibious aircraft. Also series are recognized globally as the best aerial firefighters with powerful engines and modern avionics,


Figure 15: The Amphibious Aircrafts CL-215 and CL-415

Source: (Bozeman, 2018)

They have been crucial tools in aerial firefighting for over 30 years in various countries like Italy, particularly in Sicily and Sardinia, Portugal facing similar fire risks as its Iberian neighbor Spain, especially in regions like Catalonia and Andalusia, France, particularly in the Mediterranean region, Türkiye has used these aircraft for combating forest fires, especially in coastal regions, Morocco and in Chile, with its diverse topography and forested regions.

Both aircraft are renowned for their effectiveness in aerial firefighting, particularly in regions with accessible water sources for scooping.

Amphibious aircraft named "Scoopers" may refill itself in 12 seconds from sources that are 300 feet wide and 6.6 feet deep by skimming the surface of a body of water. It is specifically designed for tight maneuvering at low altitudes and airspeeds over difficult mountainous terrain and Scoopers are commonly used in direct attacks to cool down the fire temperature or to stop fire edges from crossing fire lines. Their ability to operate in rugged and remote areas makes them invaluable assets in combating forest fires and in various utility roles.

Here's a brief overview of each:

A. Canadair CL-215 (Bombardier 215)

Figure 16, the CL-215 was introduced in the 1960s precisely in 1969 by Canadair, a Canadian aircraft manufacturer. It is a twin-engine (18-cyl air-cooled radial piston engines or turbine engine), high-wing aircraft primarily designed for water bombing in firefighting operations. Its amphibious design allows it to operate on both water and land. One of the unique features of the CL-215 is its ability to scoop water from lakes or reservoirs while in flight, which it can then drop over fires (White, 2021). Besides firefighting, the CL-215 has been used for search and rescue, cargo transport, and as a passenger aircraft (18 passengers or equivalent cargo).

Figure 16: Canadair CL-215

Source: (White, 2021)

Canadair CL-215 Specifications:

- Type: Amphibious water bomber
- Engines: Twin Pratt & Whitney R-2800 radial piston engines
- Power: 2,100 hp each
- Wingspan: 93 feet 10 inches (28.60 meters)
- Length: 65 feet 1 inch (19.84 meters)
- Height: 29 feet 10 inches (9.09 meters)
- Max Takeoff Weight: 43,000 pounds (19,505 kg)
- Water Capacity: 1,400 US gallons (4,900 liters)
- Range: 1,300 miles (2,092 km)
- Speed: 180 mph (290 km/h)

B. CL-415 (Viking 415)

The CL-415 is an advanced version of the CL-215, introduced by Bombardier in the 1990s. It is sometimes referred to as the Bombardier 215 after Bombardier's acquisition of Canadair, and as Viking 415 after Viking Air acquired the type certificates for all out-of-production Bombardier aircraft. The aircraft can carry up to 1,620 US gallons (6,140 liters) of water, mix it with a chemical foam if desired, and drop it on a fire without having to return to base to refill its tanks or deliver it accurately to the fire zone as shown on Figure 17 below,

Figure 17: Canadair CL-415

Source: (Harris M. , 2022)

Canadair CL-415 (Viking 415) Specifications:

- Type: Amphibious water bomber
- Engines: Twin Pratt & Whitney Canada PW123AF turboprops
- Power: 2,380 shp each
- Wingspan: 93 feet 10 inches (28.60 meters)
- Length: 65 feet 1 inch (19.84 meters)
- Height: 29 feet 10 inches (9.09 meters)
- Max Takeoff Weight: 47,000 pounds (21,320 kg)
- Water Capacity: 1,620 US gallons (6,140 liters)
- Range: 1,600 miles (2,575 km)
- Speed: 233 mph (376 km/h)

Compared to its predecessor, this aircraft has a number of improvements, such as a stronger and efficient turboprop power plants, Canadair began on the project of equipping the CL-215 aircraft with improved avionics, more water carrying capacity, and Pratt & Whitney Canada PW123AF engines. The CL-415 has the same ability to scoop water from adjacent bodies of water as the CL-215.

It is quite excellent in fighting fires because of its agility and effectiveness while dropping water. Because of its amphibious qualities, it is also utilized for a variety of tasks such cargo transport, patrol, and search and rescue. In order to achieve better performance, the aircraft underwent extensive modernization and advancements over the CL-215, especially in the areas of aerodynamics and the cockpit (Harris M. , 2022).

2. The Air Tractor "Fire Boss"

The Air Tractor Fire Boss is a specialized aerial firefighting aircraft, adapted from the Air Tractor AT-802 agricultural plane. It is amphibious, allowing it to scoop up water from lakes and rivers efficiently. That means, it can fill its tank in just a few seconds while skimming over a water surface. With a capacity of up to 800 US gallons (about 3,030 liters) of water or fire retardant, it excels in rapid, repeated attacks on wildfires, particularly during early stages to prevent spread. Figure 18 below,

Figure 18: The Air Tractor "Fire Boss

Source: (Shanti, 2023)

Air Tractor "Fire Boss" Specifications:

- Type: Amphibious single-engine air tanker
- Engines: Pratt & Whitney PT6A-67F turboprop
- Power: 1,600 shp
- Wingspan: 59 feet 3 inches (18.06 meters)

- Length: 35 feet 10 inches (10.92 meters)
- Height: 11 feet 7 inches (3.53 meters)
- Max Takeoff Weight: 16,000 pounds (7,257 kg)
- Water Capacity: 800 US gallons (3,030 liters)
- Range: 1,000 miles (1,609 km)
- Speed: 200 mph (322 km/h)

The Air Tractor Fire Boss has proven its effectiveness in firefighting across various regions worldwide. In the United States, it is frequently deployed in wildfire-prone states like California, Oregon, and Washington, particularly in rural and forested areas. Canadian provinces with extensive forests, such as British Columbia and Ontario, also utilize the Fire Boss. Its effectiveness during Australia's bushfire season, especially in areas near water sources, highlights its adaptability. Additionally, the Fire Boss is operational in several European countries like Spain, Portugal, and Greece, leveraging its ability to scoop water from the Mediterranean and Atlantic for firefighting. This global usage underlines the Fire Boss's versatility and efficiency in diverse environmental conditions and terrains (Shanti, 2023).

3. The Lockheed C-130 Hercules

The Lockheed C-130 Hercules in its firefighting configuration is a versatile, multi-role military transport aircraft adapted for aerial firefighting missions. It demonstrates the adaptability of military aircraft for civilian emergency services, providing an essential capability in controlling and managing forest fires and other large-scale natural disasters. The C-130's ability to operate from short, rough airstrips makes it particularly valuable in firefighting, as it can operate close to fire zones. Its flexibility and reliability make it a key asset in firefighting efforts. Represented on Figure 19,

Figure 19: The Lockheed C-130 Hercules

Source: (Thomas, 2022)

The primary function adapted for aerial firefighting with MAFFS a self-contained unit that can be loaded into the cargo bay and can carry up to 3,000 US gallons (approximately 11,356 liters) of water or fire retardant. This allows the aircraft to cover a substantial area in a single pass.

Lockheed C-130 Hercules Specifications:

- Type: Military transport aircraft adapted for firefighting
- Engines: Four Allison T56-A-15 turboprops
- Power: 4,590 shp each
- Wingspan: 132 feet 7 inches (40.41 meters)
- Length: 97 feet 9 inches (29.79 meters)
- Height: 38 feet 3 inches (11.66 meters)
- Max Takeoff Weight: 155,000 pounds (70,307 kg)
- Firefighting Capacity: 3,000 US gallons (11,356 liters) with MAFFS
- Range: 2,360 miles (3,800 km)
- Speed: 336 mph (541 km/h)

MAFFS-equipped C-130s are used by the U.S. Air Force Reserve and Air National Guard for firefighting missions. The aircraft's speed, maneuverability, and payload capacity make it highly effective for rapid response in combating wildfires, especially in remote or rugged terrain.

Designed specifically as a combat transport, the aircraft featured a hinged loading ramp at the rear of the fuselage for efficient loading and unloading. A significant advancement for large aircraft was the integration of the Allison T56 turboprop power plant, developed for the C-130. This engine provided greater range compared to turbojet engines due to its lower fuel consumption. Additionally, turboprop engines offered significantly more power for their weight than traditional piston engines (Thomas, 2022).

4. Beriev Be-200 'T-tailed Taganrog Turbine'

The Beriev Be-200 on Figure 20, colloquially known as the 'T-tailed Taganrog Turbine,' is a Russian amphibious aircraft designed for a variety of roles, including aerial firefighting, it can operate on land and scoop up large amounts of water in 12 seconds while skimming over a water surface (Kable, 2016).

Figure 20: The Beriev Be-200

Source: (Kable, 2016)

Beriev Be-200 'T-tailed Taganrog Turbine' Specifications:

- Type: Amphibious multipurpose aircraft
- Engines: Two Progress D-436TP turbofans
- Power: 16,500 lbf each
- Wingspan: 108 feet 3 inches (33.13 meters)
- Length: 102 feet 3 inches (31.14 meters)
- Height: 28 feet 10 inches (8.78 meters)
- Max Takeoff Weight: 93,000 pounds (42,000 kg)
- Water Capacity: 3,170 US gallons (12,000 liters)

- Range: 2,051 miles (3,300 km)
- Speed: 435 mph (700 km/h)

The Be-200 has been employed in various regions for firefighting operations, owing to its unique water-scooping ability and versatility. Extensively used in Russia for combating forest and steppe fires, especially in remote and hard-to-reach areas. Deployed in Greece for firefighting, particularly effective during the country's severe summer wildfires. In Portugal for aerial firefighting operations, aiding in controlling large forest fires, in Israel to combat significant forest fires. Mediterranean countries, Italy and Spain have also used for firefighting, benefiting from its amphibious capabilities.

C. Decision Makers

Decision makers are the pilots who fly the firefighting fixed winged aircraft at General Directorate of Forestry (GDF) and Turkish Aeronautical Association (THK). They have information all the aircraft which are determined as alternatives. They composed of a significant number of all pilots at GDF.

5.5 Data

This study focuses on identifying the optimal aircraft model for forest firefighting operations in Türkiye. Utilizing a systematic evaluation framework that incorporates the AHP, TOPSIS, and MOORA methodologies, the study aims to provide a comprehensive analysis to improve the wildfire management by enhancing safety and protect natural resources. The decision makers or the experts in fields relevant to aerial firefighting and aviation assess five different aircraft based on a set of predetermined three main criteria and seven sub-criteria.

The evaluation criteria are divided into three main categories, each encompassing specific sub-criteria vital for the aircraft's operational effectiveness in firefighting: Technical Performance (This includes flight duration, water tank capacity, aerodynamic characteristics, engine power, and refill efficiency) These factors determine the aircraft's capability to perform in diverse and challenging firefighting scenarios. Hourly Operational Cost (This includes fuel cost efficiency, maintenance costs and Labor Cost) which are critical for cost-effective operations over the aircraft's service life. Purpose Built: (this criterion focuses on amphibious and retrofit) are assessed to determine the aircraft's versatility and adaptability to firefighting tasks. Data collection is executed in two phases, integrating both qualitative and quantitative approaches:

Phase 1: Expert Judgments via AHP/FAHP

- **Expert Selection and Training:** A panel of the decision makers who are the Pilots/experts with comprehensive backgrounds in aviation, operational management, and firefighting is carefully chosen. A training or explanation session is conducted to ensure a common understanding of the evaluation process and criteria, promoting consistency in their assessments.

- **Data gathering:** Questionnaires were used to collect individual judgments from the experts, with the aim of constructing Pairwise Comparison Matrices (PCMs) for the 3 main and 7 sub-criteria levels. The questionnaires employed a five-point fundamental scale as suggested by Saaty (1990), which is detailed in Section 4.4 of this document. This step is crucial as it establishes the relative importance of each factor or the weightage used in the final selection process.

Phase 2: Aircraft Evaluation via Fuzzy TOPSIS and MOORA

The analysis of the gathered data will be conducted using MCDM tools specifically designed for FAHP based on Fuzzy TOPSIS, and MOORA calculations. This ensures precise and reliable computation of weights, scores, and rankings, facilitating objective and robust decision-making.

- **Aircraft Data Compilation (Quantitative Data)**: Comprehensive data on the technical specifications, operational performance, and cost parameters of the five selected aircraft models are gathered from various sources including published articles, GDF, manufacturers' datasheets and operational records.

- **Scoring by Experts (Qualitative Data)**: Using the weights derived from the Fuzzy AHP process, experts assign scores to each aircraft across all sub-criteria. These scores are then aggregated into a decision matrix.
- **Application of Fuzzy TOPSIS and MOORA:** The decision matrix is analyzed through Fuzzy TOPSIS to rank the aircraft by their proximity to the ideal solution and through MOORA to evaluate them based on an optimized ratio analysis.

By employing a detailed and structured data collection approach, this study will objectively assess the suitability of various aircraft models for forest firefighting in Türkiye. The combination of expert knowledge and sophisticated multi criteria decision-making tools will help identify the aircraft that best meets the operational requirements and effectiveness criteria for firefighting tasks. This comprehensive evaluation will support more efficient and effective firefighting operations, enhancing response capabilities in forest fire scenarios by achieving the study goal.

5.6 The Limitation of the Study and Data Collection Process

The study "MCDM Approach for The Best Aircraft Model Selection for Forest Firefighting in Türkiye" employs sophisticated multi criteria decision-making methods like AHP, TOPSIS, and MOORA, but it faces several limitations that could impact its outcomes. The reliance on the subjective judgments of only 6 experts raises concerns about potential biases and limits the diversity of insights, which could be mitigated by involving a larger, more varied panel. Additionally, the accuracy of the data collected, predominantly from manufacturers' specifications and operational records, might be compromised if the data are outdated or inconsistently reported.

This reliance on possibly flawed data can affect the precision of the aircraft evaluations. Moreover, the methodologies used, while robust, come with their own sets of limitations; AHP can become unwieldy with an increase in criteria, and both Fuzzy TOPSIS and MOORA might not effectively address interdependencies among criteria, thus questioning the comprehensiveness of the evaluation process.

CHAPTER 6

RESULTS AND DISCUSSION

In this chapter, results explore and compare two distinct multi-criteria decision-making approaches for selecting the best aircraft model for forest firefighting operations. Initially, the results derived from the FAHP method are detailed, providing foundational insights based on hierarchical criteria weighting. Subsequent sections delve into the outcomes obtained from the TOPSIS and MOORA methods, each offering a unique perspective on decision-making by prioritizing alternative models through different evaluative lenses. The analysis culminates with an integrated examination of hybrid methodologies, specifically FAHP based on Fuzzy TOPSIS and MOORA, where the combined strengths of FAHP with each respective method are utilized to refine and validate the selection process. A comparative analysis of these integrated approaches is presented, highlighting their efficacy and practical implications in enhancing decision accuracy and robustness in the context of forest firefighting."

6.1 Consistency Check Results

The initial phase of the model involves the utilization of AHP to analyze expert judgments, employing Saaty's consistency ratio to ensure reliable pairwise comparisons. Before aggregating the judgments of the experts, the consistency of each expert's PCM was verified by using Online Software Tool for the Analytic Hierarchy Process (AHP-OS) (Goepel, 2018) and are presented in Appendix C. As previously discussed in Section 4.2, the Consistency Ratio (CR) values should be below 0.10 for acceptability and the “CR” of 0.00 indicates perfect consistency among all judgments. Hourly Operational Cost has no sub-criteria which means no need to compute the level 2 PCM.

All the experts met this consistency criterion and were included in the study as Table 16 shows,

Table 16: Aggregated PCM

Decision Makers	CR for Level 1 in %	CR for level 2 C_1 sub-criteria in %	CR for C_3 sub-criteria in %
First DM	0,000	0,067	0,000
Second DM	0,000	0,066	0,000
Third DM	0,056	0,034	0,000
Fourth DM	0,040	0,086	0,000

Source: Compiled by the Author

6.2 Weighting Results

To determine the weights of criteria and explore their interactions, the Pairwise Comparison Matrices (PCMs) created using expert judgments for the AHP method and these comparisons are then converted into FN(s); as previously discussed in Section 4.2 to address inherent uncertainties and provide more nuanced Local weightings of the main criteria and sub-criteria in the tables. The Fuzzy AHP approach results presented in the (Table 17-19) below show PCM using FAHP Method with their weights,

Table 17: Local Weights of Main Criteria

MAIN CRITERIA	C_1: Technical Performance	C_2: Hourly Operational Cost	C_3: Purpose Built
C1: Technical Performance	(1;1;1)	(1;1;1)	(1/7;1/5;1/3)
C2: Hourly Operational Cost	(1;1;1)	(1;1;1)	(1/7;1/5;1/3)
C3: Purpose Built	(3;5;7)	(3;5;7)	(1;1;1)
Main criteria	Normalized Fuzzy Weights (NFW)	Normalized Crisp Weights (NCW)	
C_1: Technical Performance	(0,402; 0,122; 0,333)	0,329	
C_2: Hourly Operational Cost	(0,035; 0,007; 0,333)	0,327	
C_3: Purpose Built	(0,563; 0,871; 0,333)	0,343	

Source: Compiled by the Author

Table 18: Local Weights of Technical Performance Sub-Criteria

C_1: Technical Performance	Flight Duration	Water Tanker Capacity	Aerodynamic characteristics	Engine Power	Refill
C_{11}: Flight Duration	(1;1;1)	(1;2;7)	(1/9;11/7;7)	(1/9;4/7;1)	(1/9;52/9;9)
C_{12}: Water Tanker Capacity	(1/7;4/5;1)	(1;1;1)	(1/9;25/9;9)	(1;1;1)	(1/9;44/7;9)
C_{13}: Aerodynamic characteristics	(1/7;19/5;11)	(1/9;25/9;9)	(1;1;1)	(1/9;7/9;1)	(1;6;9)
C_{14}: Engine Power	(1;9/2;9)	(1;1;1)	(1;3;9)	(1;1;1)	(1/9;44/7;9)
C_{15}: Refill	(1/9;7/3;9)	(1/9;11/6;9)	(1/9;1/3;1)	(1/9;11/6;9)	(1;1;1)

C_1: Technical Performance' Sub-criteria	Normalized Fuzzy Weights (NFW)	Normalized Crisp Weights (NCW)
C_{11}: Flight Duration	(0,162; 0,174; 0,199)	0,196
C_{12}: Water Tanker Capacity	(0,171; 0,193; 0,142)	0,146
C_{13}: Aerodynamic characteristics	(0,171; 0,237; 0,220)	0,221
C_{14}: Engine Power	(0,391; 0,264; 0,220)	0,225
C_{15}: Refill	(0,105; 0,132; 0,220)	0,211

Table 19: Local Weights of Purpose-Built Sub-Criteria

C_3: Purpose Built	Amphibious	Retrofit	Normalized Fuzzy Weights (NFW)	Normalized Crisp Weights (NCW)
C_{32}: Amphibious	(1;1;1)	(5;8;9)	(0,978; 0,985; 0,978)	0,980
C_{32}: Retrofit	(1/9;1/8;1/5)	(1;1;1)	(0,022; 0,015; 0,022)	0,020

Source: Compiled by the Author

Table 20 illustrates the structured weighting framework used in the FAHP converted into CN to determine the optimal aircraft model for forest firefighting. It combines the local weights of main and sub-criteria to compute global weights, essential for assessing each factor's comprehensive impact on decision-making. Each sub-criterion's local weight is multiplied by its respective main criterion's local weight to generate a global weight,

Table 20: Global Weights with CN

Main Criteria	Main Criteria Local Weights	Sub- Criteria	Sub- Criteria Local Weights	Global Weights
Technical Performance	0,329	Flight Duration	0,196	0,065
		Water Tanker Capacity	0,146	0,048
		Aerodynamic characteristics	0,221	0,073
		Engine Power	0,225	0,074
		Refill	0,211	0,070
Purpose Built	0,343	Amphibious	0,980	0,337
		Retrofit	0,020	0,007
Hourly Operational Cost	0,327			0,327
SUM				**1**

Source: Compiled by the Author

In addition, Table 21 illustrates the structured weighting framework used in the FAHP to determine the optimal aircraft model for forest firefighting,

Table 21: Global Weights with FN

C1: Technical Performance: Sub-criteria Normalized Fuzzy Weights (NFW)	(0,402; 0,122; 0,333)	Global Weights	
C11: Flight Duration	(0,162; 0,174; 0,199)	**C11**	(0,065; 0,021; 0,066)
C12: Water Tanker Capacity	(0,171; 0,193; 0,142)	**C12**	(0,069; 0,024; 0,047)
C13: Aerodynamic characteristics	(0,171; 0,237; 0,220)	**C13**	(0,069; 0,029; 0,073)
C14: Engine Power	(0,391; 0,264; 0,220)	**C14**	(0,157; 0,032;0,073)
C15: Refill	(0,105; 0,132; 0,220)	**C15**	(0,042; 0,016; 0,073)
C2: Hourly Operational Cost	(0,035; 0,007; 0,333)		
C3: Purpose Built: Sub-criteria Normalized Fuzzy Weights (NFW)	(0,563; 0,871; 0,333)	Global Weights	
C32: Amphibious	(0,978; 0,985; 0,978)	**C31**	(0,551; 0,858; 0,326)
C32: Retrofit	(0,022; 0,015; 0,022)	**C32**	(0,012; 0.013; 0,007)

Source: Compiled by the Author

6.3 Evaluation Results

This study employs two advanced MCDM methods, Fuzzy TOPSIS and MOORA, to evaluate and select the most suitable aircraft model for forest firefighting efforts in Türkiye. The analysis includes five widely used firefighting aircraft: Canadair CL-215, Canadair CL-415, Air Tractor "Fire Boss", Lockheed C-130 Hercules, and Beriev Be-200.

The evaluation framework utilizes three main criteria; Technical Performance, Hourly Operational Cost, and Purpose Built further divided into seven sub-criteria including Flight Duration, Water Tank Capacity, Aerodynamic Characteristics, Engine Power, Refill, Amphibious capabilities, and Retrofit options. Firefighting pilots or experts contributed to this evaluation, using a five-point scale to assess each aircraft's suitability based on the defined criteria and sub-criteria. The results to the problem using those methods have been implemented, and the steps are shown below one by one.

A. Results of FAHP- FTOPSIS Approach

At this stage, the individual assessments were combined to form the decision matrix for the fuzzy TOPSIS method by calculating the average data given by Decision Makers, which is outlined in the table below. This matrix reflects the aggregated performance values of each alternative under the sub-criteria, enabling a structured evaluation of the best aircraft model selection.

Step 1 Creating the Decision Matrix in this study

The decision matrix for the TOPSIS method, structured into a 5x9 format, represents alternatives in rows and criteria in columns. This matrix, crucial for evaluating the best aircraft model selection for forest firefighting, incorporates data sourced from published articles, aircraft manufacturers' datasheets, and operational records, along with expert assessments rated on a 5-point scale. Construct the fuzzy decision matrix

$$X_{ij} = \left(\mathrm{a}_{ij}, \mathrm{b}_{ij}, \mathrm{c}_{ij}\right) \tag{17}$$

Where X_{ij} represents the performance of alternative "i" with respect to criterion "j". As shown in the Table 22, by considering the expert judgement using the linguistic variables discussed in the 4.3.1 section.

Table 22: TOPSIS Method Performance Values

DECISION Matrix	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{31}	C_{32}
Canadair CL-215	3	408	4.900	(0;3,5;8)	(0;4,5;8)	(4;5,5;8)	(0;1;2)
Canadair CL-415	4	512	6.140	(6;8,5;10)	(6;8,5;10)	(6;8,5;10)	(0;1;2)
Air Tractor "Fire Boss"	3	203	3.070	(6;7,5;10)	(4;7;10)	(6;7,5;10)	(0;1;2)
Lockheed C-130 Hercules	8	14	11.000	(4;5;6)	(2;4,5;6)	(0;1;2)	(2;4,5;6)
Beriev Be-200	3	1.000	12.010	(2;4,5;8)	(2;6;10)	(4;6,5;8)	(0;1;2)

Source: Compiled by the Author

Step 2: Creating the Normalization of the Fuzzy Decision Matrix

Normalization of the Fuzzy Decision Matrix is obtained by calculating the elements of the fuzzy decision matrix to reduce bias from different units or scales of measurement using the formula (6) as shown in the Table 23,

Step 3 Weighted Normalized Decision Matrix

The normalized scores are then weighted according to the importance of each criterion and sub-criterion, previously determined using the FAHP method. This step involves multiplying each element of the Normalized Decision Matrix by the corresponding importance degrees of the criteria, as demonstrated in the Table 24 using the specified formula (7),

A collection of numbers representing the relative weights of the criteria or options is the end product as shown in the Table 25.

Table 23: The F-TOPSIS Normalize Decision Matrix

Aircraft	C11	C12	C13	C14	C15
Canadair CL-215	(0,375; 0,375; 0,375)	(0,034; 0,034; 0,034)	(0,408; 0,408; 0,408)	(0; 0,35; 0,8)	(0; 0,45; 0,8)
Canadair CL-415	(0,5; 0,5; 0,5)	(0,027; 0,027; 0,027)	(0,511; 0,511; 0,511)	(0,6; 0,85; 1)	(0,6; 0,85; 1)
Air Tractor "Fire Boss"	(0,375; 0,375; 0,375)	(0,069; 0,069; 0,069)	(0,256; 0,256; 0,256)	(0,6; 0,75; 1)	(0,4; 0,7; 1)
Lockheed C-130 Hercules	(1; 1; 1)	(1; 1; 1)	(0,916; 0,916; 0,916)	(0,4; 0,45; 0,6)	(0,2; 0,45; 0,6)
Beriev Be-200	(0,375; 0,375; 0,375)	(0,014; 0,014; 0,014)	(1; 1; 1)	(0,2; 0,45; 0,8)	(0,2; 0,6; 1)

Aircraft	C31	C32
Canadair CL-215	(0,4; 0,55; 0,8)	(0; 0,167; 0,333)
Canadair CL-415	(0,6; 0,85; 1)	(0; 0,167; 0,333)
Air Tractor "Fire Boss"	(0,6; 0,75; 1)	(0; 0,167; 0,333)
Lockheed C-130 Hercules	(0; 0,1; 0,2)	(0,333; 0,75; 1)
Beriev Be-200	(0,4; 0,65; 0,8)	(0; 0,167; 0,333)

Source: Compiled by the Author

Table 24: Weighted Normalized F-TOPSIS Decision Matrix

	C11	**C12**	**C13**	**C14**	**C15**
Global Weights	(0,065; 0,021; 0,066)	(0,069; 0,024; 0,047)	(0,069; 0,029; 0,073)	(0,157; 0,032; 0,073)	(0,042; 0,016; 0,073)
Aircraft	**C11**	**C12**	**C13**	**C14**	**C15**
Canadair CL-215	(0,375; 0,375; 0,375)	(0,034; 0,034; 0,034)	(0,408; 0,408; 0,408)	(0; 0,35; 0,8)	(0; 0,45; 0,8)
Canadair CL-415	(0,5; 0,5; 0,5)	(0,027; 0,027; 0,027)	(0,511; 0,511; 0,511)	(0,6; 0,85; 1)	(0,6; 0,85; 1)
Air Tractor "Fire Boss"	(0,375; 0,375; 0,375)	(0,069; 0,069; 0,069)	(0,256; 0,256; 0,256)	(0,6; 0,75; 1)	(0,4; 0,7; 1)
Lockheed C-130 Hercules	(1; 1; 1)	(1; 1; 1)	(0,916; 0,916; 0,916)	(0,4; 0,45; 0,6)	(0,2; 0,45; 0,6)
Beriev Be-200	(0,375; 0,375; 0,375)	(0,014; 0,014; 0,014)	(1; 1; 1)	(0,2; 0,45; 0,8)	(0,2; 0,6; 1)

	C31	**C32**
Global Weights	(0,551; 0,858; 0,326)	(0,012; 0,013; 0,007)
Aircraft	**C31**	**C32**
Canadair CL-215	(0,4; 0,55; 0,8)	(0; 0,167; 0,333)
Canadair CL-415	(0,6; 0,85; 1)	(0; 0,167; 0,333)
Air Tractor "Fire Boss"	(0,6; 0,75; 1)	(0; 0,167; 0,333)
Lockheed C-130 Hercules	(0; 0,1; 0,2)	(0,333; 0,75; 1)
Beriev Be-200	(0,4; 0,65; 0,8)	(0; 0,167; 0,333)

Source: Compiled by the Author

Table 25: Weighted Normalized F-TOPSIS Decision Matrix Sub-Criteria

Aircraft	C11	C12	C13	C14	C15
Canadair CL-215	(0,024; 0,008; 0,025)	(0,002; 0,001; 0,002)	(0,028; 0,012; 0,030)	(0,000; 0,011; 0,059)	(0,000; 0,007; 0,059)
Canadair CL-415	(0,033; 0,011; 0,033)	(0,002; 0,001; 0,001)	(0,035; 0,015; 0,037)	(0,094; 0,027; 0,073)	(0,025; 0,014; 0,073)
Air Tractor "Fire Boss"	(0,024; 0,008; 0,025)	(0,005; 0,002; 0,003)	(0,018; 0,007; 0,019)	(0,094; 0,024; 0,073)	(0,017; 0,011; 0,073)
Lockheed C-130 Hercules	(0,065; 0,021; 0,066)	(0,069; 0,024; 0,047)	(0,063; 0,026; 0,067)	(0,063; 0,014; 0,044)	(0,008; 0,007; 0,044)
Beriev Be-200	(0,024; 0,008; 0,025)	(0,001; 0,000; 0,001)	(0,069; 0,029; 0,073)	(0,031; 0,014; 0,059)	(0,008; 0,010; 0,073)

Aircraft	C31	C32
Canadair CL-215	(0,220; 0,472; 0,261)	(0,000; 0,002; 0,002)
Canadair CL-415	(0,330; 0,729; 0,326)	(0,000; 0,002; 0,002)
Air Tractor "Fire Boss"	(0,330; 0,643; 0,326)	(0,000; 0,002; 0,002)
Lockheed C-130 Hercules	(0,000; 0,086; 0,065)	(0,004; 0,010; 0,007)
Beriev Be-200	(0,220; 0,558; 0,261)	(0,000; 0,002; 0,002)

Source: Compiled by the Author

Step 4 Identification of PIS and NIS

For each criterion, the best and worst values are identified to establish the positive and negative ideal solutions. Table 26 are the ideal solution values A^+ are obtained by identifying the highest values in each column of the weighted normalized decision matrix, whereas the negative ideal solution values A^- are determined by identifying the lowest values in each column of the weighted normalized decision matrix using the specified formula (8) and (9).

Table 26: Study Results of PIS and NIS

A+	**A-**
(0,065; 0,021; 0,066)	(0,024; 0,008; 0,025)
(0,001; 0; 0,001)	(0,069; 0,024; 0,047)
(0,069; 0,029; 0,073)	(0,018; 0,007; 0,019)
(0,094; 0,027; 0,073)	(0; 0,011; 0,044)
(0,025; 0,014; 0,073)	(0; 0,007; 0,044)
(0,33; 0,729; 0,326)	(0; 0,086; 0,065)
(0,004; 0,01; 0,007)	(0; 0,002; 0,002)

Step 5 Distance Calculation

The distance of each aircraft from PIS and NIS is calculated, providing a clear quantitative measure of each aircraft's performance relative to the ideals. Table (27-28) and Figure (21-22) are the distance of each alternative to the PIS $\boldsymbol{S_i^+}$ and NIS $\boldsymbol{S_i^-}$ is calculated, typically using Euclidean distance formula (10) and (11). The distance of each alternative to the PIS using specified formula (10) discussed in the session 4.3,

Table 27: The Ideal Best Euclidean Distance

DECISION Matrix	**BC C_{11}**	**NBC C_{12}**	**BC C_{13}**	**BC C_{14}**	**BC C_{15}**	**BC C_{31}**	**BC C_{32}**	**S^+**
Canadair CL-215	0,049	0,002	0,051	0,096	0,027	0,282	0,009	0,513
Canadair CL-415	0,039	0,001	0,042	0,000	0,000	0,000	0,009	0,089
Air Tractor "Fire Boss"	0,049	0,004	0,064	0,003	0,009	0,086	0,009	0,215
Lockheed C-130 Hercules	0,000	0,077	0,007	0,038	0,025	0,739	0,000	0,732
Beriev Be-200	0,049	0,000	0,000	0,065	0,017	0,207	0,009	0,348

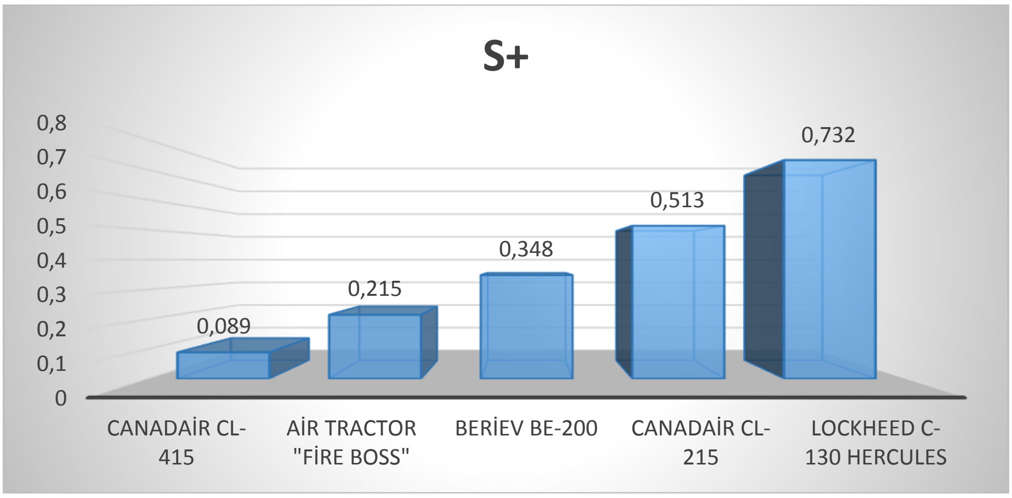

Figure 21: The Ideal Best Euclidean Distance

The distance of each alternative to the NIS using specified formula (11) discussed in the session 4.3,

Table 28: The Ideal Worst Euclidean distance

DECISION Matrix	BC	NBC	BC	BC	BC	BC	BC	S^-
	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{31}	C_{32}	
Canadair CL-215	0,000	0,075	0,013	0,008	0,008	0,459	0,000	0,414
Canadair CL-415	0,010	0,075	0,022	0,097	0,031	0,739	0,000	0,823
Air Tractor "Fire Boss"	0,000	0,072	0,000	0,097	0,024	0,665	0,000	0,714
Lockheed C-130 Hercules	0,049	0,000	0,057	0,063	0,008	0,000	0,009	0,186
Beriev Be-200	0,000	0,077	0,064	0,033	0,019	0,533	0,000	0,572

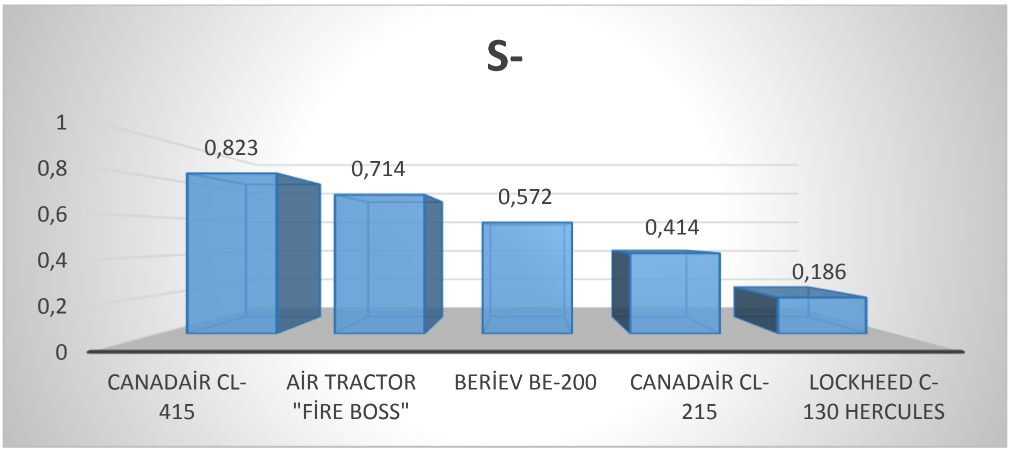

Figure 22: The Ideal Worst Euclidean distance

Step 6 Closeness Coefficient Calculation

The relative closeness of each aircraft to the ideal solution is quantitatively assessed by calculating the closeness coefficient for each option. The aircraft with the highest closeness coefficient is recommended as the most suitable, facilitating a systematic and quantitative approach to selecting the best aircraft. The relative closeness of each alternative to the Positive Ideal Solution (PIS) is determined and shown in the Table 29 and on Figure 23. This matrix, known as the performance of each alternative relative to the PIS or Performance Score "$\boldsymbol{P_i}$". Using the Equation (12),

Table 29: Results of Closeness Coefficient

DECISION Matrix	S+	S-	(S+)+(S-)	Pi
Canadair CL-215	0,513	0,414	0,927	0,447
Canadair CL-415	0,089	0,823	0,912	0,902
Air Tractor "Fire Boss"	0,215	0,714	0,929	0,769
Lockheed C-130 Hercules	0,732	0,186	0,918	0,203
Beriev Be-200	0,348	0,572	0,920	0,622

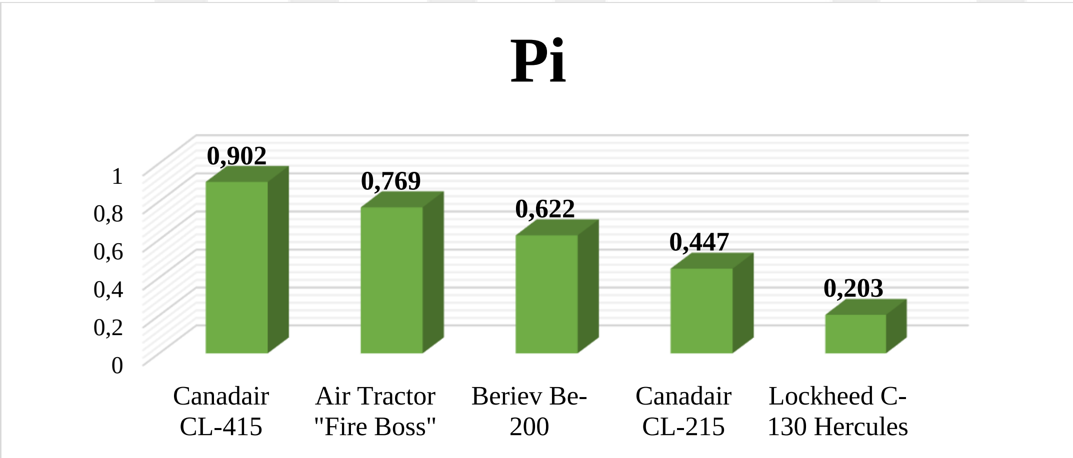

Figure 23: Results of Closeness Coefficient Calculation

Step 7. Ranking of the Alternatives

In the final step, alternatives are ranked based on their relative closeness to the Positive Ideal Solution (PIS). The alternative that exhibits the highest relative closeness is deemed the best choice, as indicated by its performance score, marking it as the most preferred option. This ranking continues in descending order, with the next best alternatives following suit as shown in the Table 30 and Figure 24.

Table 30: Aircraft Rank of the Study- Fuzzy TOPSIS Method

DECISION Matrix	Pi	Rank
Canadair CL-415	0,902	1
Air Tractor "Fire Boss"	0,769	2
Beriev Be-200	0,622	3
Canadair CL-215	0,447	4
Lockheed C-130 Hercules	0,203	5

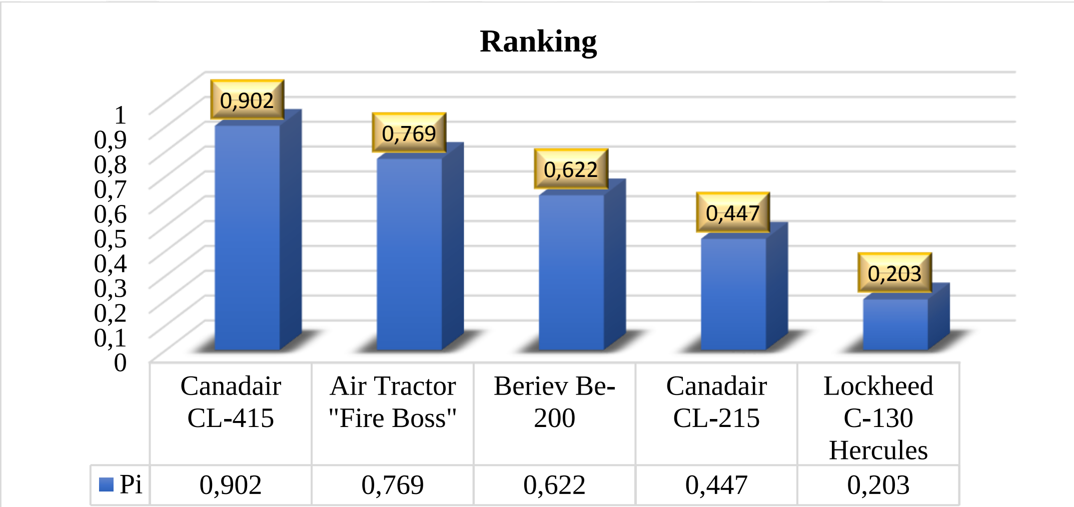

Figure 24: Aircrafts Ranking with F-TOPSIS

Source: Compiled by the Author

B. Results of FAHP-MOORA Approach

The MOORA method is a powerful MCDM tool employed to identify the optimal choice among various competing alternatives across multiple criteria. This method unfolds through a series of structured steps, each integral to the thorough evaluation and comparative analysis of the alternatives. MOORA, like TOPSIS, is utilized to evaluate the performance of the aircraft relative to the defined criteria.

Here's an outline of the procedures typically applied in the MOORA method

Step 1: Construction of the Decision Matrix

Create a decision matrix consisting of alternatives (rows) and criteria (columns). Each cell in the matrix represents the performance of an alternative concerning a specific criterion as shown in the Table 31,

Table 31: MOORA Performance Values

DECISION Matrix	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{31}	C_{32}
Canadair CL-215	3	408	4.900	2,25	2,75	3,25	1
Canadair CL-415	4	512	6.140	4,75	4,75	4,75	1
Air Tractor "Fire Boss"	3	203	3.070	4,25	4	4,25	1
Lockheed C-130 Hercules	8	14	11.000	3	2,75	1	2,75
Beriev Be-200	3	1.000	12.010	2,75	3,5	3,75	1
Sum of Square Root	10,344	1.212,44	18.340,5	7,89	8,12	8,139	3,4

Source: Compiled by the Author

Step 2: Normalize the Decision Matrix

In MOORA, The Normalization decision matrix is essential to make the criterion values dimensionless and comparable as shown in the Table 32. Normalization is often done using the ratio system, where each element of the decision matrix is divided by the square root of the sum of the squares for each criterion by calculating the elements of the decision matrix using the formula (6),

Table 32: MOORA Normalize Decision Matrix

DECISION Matrix	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{31}	C_{32}
Canadair CL-215	0,29	0,337	0,267	0,285	0,339	0,399	0,294
Canadair CL-415	0,387	0,422	0,335	0,602	0,585	0,584	0,294
Air Tractor "Fire Boss"	0,29	0,167	0,167	0,539	0,493	0,522	0,294
Lockheed C-130 Hercules	0,773	0,012	0,6	0,38	0,339	0,123	0,809
Beriev Be-200	0,29	0,825	0,655	0,349	0,431	0,461	0,294

Step 3: Weighted Normalized Matrix

In MOORA weighting the normalization matrix is done and presented in Table 33, when weights from FAHP are assigned to the criteria reflecting their relative importance, and the normalized values are multiplied by these weights using the formula (7),

Table 33: MOORA Weighted Normalized Decision Matrix

	BC	**NBC**	**BC**	**BC**	**BC**	**BC**	**BC**
DECISION Matrix	**C_{11}**	**C_{12}**	**C_{13}**	**C_{14}**	**C_{15}**	**C_{31}**	**C_{32}**
Canadair CL-215	0,019	0,016	0,019	0,021	0,024	0,134	0,002
Canadair CL-415	0,025	0,020	0,024	0,045	0,041	0,197	0,002
Air Tractor "Fire Boss"	0,019	0,008	0,012	0,040	0,034	0,176	0,002
Lockheed C-130 Hercules	0,050	0,001	0,044	0,028	0,024	0,041	0,006
Beriev Be-200	0,019	0,040	0,048	0,026	0,030	0,155	0,002

Source: Compiled by the Author

Step 4: Apply the Ratio System

Summing the normalized values for the favorable criteria and deducting the normalized values for the non-beneficial (cost) criterion yields a performance score for each choice Table (34-35):

Table 34: MOORA Performance Score Results

	BC	**NBC**	**BC**	**BC**	**BC**	**BC**	**BC**
DECISION Matrix	**C_{11}**	**C_{12}**	**C_{13}**	**C_{14}**	**C_{15}**	**C_{31}**	**C_{32}**
Canadair CL-215	0,019	0,016	0,019	0,021	0,024	0,134	0,002
Canadair CL-415	0,025	0,020	0,024	0,045	0,041	0,197	0,002
Air Tractor "Fire Boss"	0,019	0,008	0,012	0,040	0,034	0,176	0,002
Lockheed C-130 Hercules	0,050	0,001	0,044	0,028	0,024	0,041	0,006
Beriev Be-200	0,019	0,040	0,048	0,026	0,030	0,155	0,002

Table 35: Aircraft Performance Score

DECISION Matrix	**Yi**
Canadair CL-215	0,203
Canadair CL-415	0,313
Air Tractor "Fire Boss"	0,275
Lockheed C-130 Hercules	0,192
Beriev Be-200	0,240

Source: Compiled by the Author

Step 5: Rank the Alternatives

Rank the alternatives/Aircrafts based on the computed scores from either the ratio system or the reference point assessment. Table 36 and Figure 25 illustrate the alternative with the highest score is considered the best,

Table 36: Aircraft Ranking with MOORA

DECISION Matrix	Yi	Rank
Canadair CL-415	0,314	**1**
Air Tractor "Fire Boss"	0,275	**2**
Beriev Be-200	0,240	**3**
Canadair CL-215	0,204	**4**
Lockheed C-130 Hercules	0,192	**5**

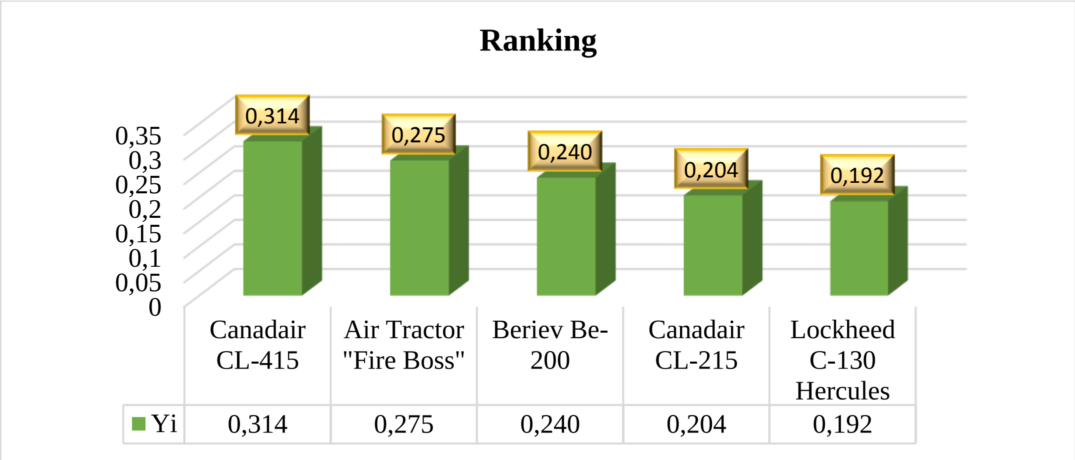

Figure 25: Aircrafts Ranking with MOORA Method

6.4 Discussion

The study's findings are significant in that they offer valuable insights for decision-makers in selecting the most effective aircraft for wildfire management. By focusing on specific regions frequently affected by fires, the research provides a detailed understanding of the practical application of various aircraft models in real-world scenarios. This comprehensive analysis not only contributes to the protection of valuable natural resources but also enhances the overall safety and efficiency of firefighting operations in Türkiye. The involvement of key stakeholders, including government agencies and private aerial contractors, ensures that the recommendations are practical and actionable, ultimately supporting informed decision-making processes and improving the effectiveness of forest firefighting efforts.

The study evaluates five aircraft models for forest firefighting in Türkiye using selected three main criteria and seven sub-criteria: Technical Performance, Hourly Operating Cost, and Purpose-Built Structure. Technical Performance includes Flight Duration, Water Tank Capacity, Aerodynamic Characteristics, Engine Power, and Refill Capability. Hourly Operating Cost encompasses fuel, maintenance, and labor costs. Purpose-Built Structure includes Amphibious and Retrofit capabilities. Several aircraft alternatives were considered, including the Canadair CL-215, Canadair CL-415, Air Tractor "Fire Boss," Lockheed C-130 Hercules, and Beriev Be-200. The Canadair CL-215, an amphibious aircraft with two turboprop engines, is capable of scooping water from seas or lakes. The Canadair CL-415, an improved version of the CL-215, features better engines, increased water capacity, and enhanced avionics. The Air Tractor "Fire Boss" is known for its rapid refilling capability and agility, featuring a single turboprop engine. The Lockheed C-130 Hercules is a versatile aircraft equipped with the MAFF system and four turboprop engines, capable of operating from short and rough airstrips. The Beriev Be-200 is an amphibious aircraft with a T-tailed design and four turbofan engines, capable of scooping water while skimming over water surfaces.

The most critical factor is amphibious capability, with a weight of 0.337, highlighting the importance of an aircraft's ability to operate on both land and water. This feature allows for quick and efficient water refilling from nearby sources, significantly enhancing operational effectiveness and flexibility. Engine power, weighted at 0.074, is vital for performance, speed, and load-carrying capacity. It ensures the aircraft can handle demanding firefighting missions and operate in challenging environments. Aerodynamic characteristics, with a weight of 0.073, are essential for improving fuel efficiency, maneuverability, and stability. Good aerodynamics are crucial for effective operations in complex terrains and varying weather conditions. The refill capability, weighted at 0.070, impacts the efficiency of water or fire-retardant tank replenishment. Faster refill times enable more frequent drops on active fire zones, increasing firefighting effectiveness. Flight duration, with a weight of 0.065, determines how long the aircraft can stay airborne, reducing the need for frequent refueling and allowing for extended missions. Water tanker capacity, weighted at 0.048, is important but less critical. Larger tanks allow for significant drops, covering larger fire areas in a single pass. Retrofit capability, with the lowest weight of 0.007, is the least important criterion. While beneficial, it is not as critical as the other factors in operational and performance contexts.

The results reveal that the Canadair CL-415 consistently ranks first across all evaluation methods due to its superior technical performance, advanced avionics, increased water capacity, and amphibious capabilities. The Air Tractor "Fire Boss" ranks second, recognized for its agility and rapid refilling capability. The Beriev Be-200 ranks third, appreciated for its versatility and amphibious design. The Canadair CL-215 ranks fourth, reliable but surpassed by the CL-415. The Lockheed C-130 Hercules ranks fifth, versatile but less efficient in refill time and maneuverability.

Geographical and climatic considerations are crucial for selecting suitable firefighting aircraft in Türkiye. The country's varied terrain and weather conditions, especially during the dry season, necessitate versatile and efficient aircraft. Amphibious aircraft like the CL-415 and Be-200 are particularly advantageous due to their operational flexibility and effectiveness in different firefighting scenarios.

Advantages of the best Aircraft

The **Canadair CL-415** is the top-ranked aircraft according to both the FUZZY TOPSIS and MOORA methods, scoring 0.902 and 0.314, respectively. This aircraft is exceptionally well-suited for Türkiye's diverse geography. Its amphibious capabilities allow for quick water scoops and operations on both water and land, which is essential for areas with numerous lakes and extensive coastlines. The CL-415 is equipped with two turboprop engines, providing Short Takeoff and Landing (STOL) capabilities, excellent fuel efficiency, and enhanced maneuverability. These features are ideal for operating in Türkiye's mountainous regions. The aircraft offers excellent operational flexibility, with low-altitude and slow-speed capabilities that are crucial for effective wildfire suppression. Additionally, its high-water tank capacity supports prolonged firefighting missions. The ability to rapidly refill from lakes or seas minimizes turnaround time, which is crucial during Türkiye's dry season when wildfires are more prevalent.

The **Air Tractor "Fire Boss**" is the second-ranked aircraft, with scores of 0.769 in FUZZY TOPSIS and 0.275 in MOORA. This aircraft offers significant benefits for Türkiye, particularly its rapid refilling capabilities from water bodies and its ability to operate on both water and land. Its single turboprop engine ensures excellent fuel efficiency and maneuverability, making it perfect for precision firefighting in mountainous areas. The "Fire Boss" is highly agile, with low-altitude and slow-speed capabilities that are essential for effective wildfire suppression. Although it has a smaller water tank capacity compared to the CL-415, it is adequate for initial attack strategies and ensures a quick turnaround time, which is essential for timely responses in widespread fire zones.

The **Beriev Be-200** excels in Türkiye's extensive coastline and numerous lakes with its amphibious, ranks third, with scores of 0.622 in FUZZY TOPSIS and 0.24 in MOORA. This aircraft excels in areas with extensive coastlines and numerous lakes, like those found in Türkiye, due to its amphibious T-tailed design that enables effective water scooping. Its four turbofan engines provide high speed, allowing it to cover large distances quickly and offer heavy lift capabilities suitable for expansive forest areas. The Be-200 also provides excellent maneuverability in varied terrains and weather conditions. It has a significant water capacity, making it suitable for extensive firefighting missions. Its efficient water scooping ability allows for quick refueling, which is vital for continuous operations in fire-prone regions.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

This thesis, titled "Multi Criteria Decision Making Approach for the Best Aircraft Model Selection for Forest Firefighting in Türkiye, aimed to identify the most suitable aircraft models to enhance the efficiency and effectiveness of wildfire management efforts in Türkiye. By involving forest firefighter pilots and key decision-makers in firefighting aircraft procurement, who possess access to credible information on aircraft models, the study ensured that the evaluations were grounded in practical expertise and relevant knowledge. Data were collected through face-to-face surveys with firefighting Pilots, ensuring comprehensive and accurate input.

Türkiye is highly vulnerable to wildfires, especially during dry periods. Effective aerial firefighting is crucial for protecting the country's natural resources and mitigating the devastating impact of wildfires. This study provides essential strategic insights into selecting the most appropriate aircraft models, which is vital for improving wildfire management and safeguarding Türkiye's natural environment. The study employs a MCDM approach, specifically using FUZZY AHP combined with FUZZY TOPSIS and MOORA methods. These methodologies offer a comprehensive framework for evaluating and ranking aircraft based on a set of weighted criteria and sub-criteria. This robust and systematic approach addresses the complexities involved in selecting the best aircraft models for forest firefighting.

The evaluation results highlight that technical performance and purpose-built structures are the most significant criteria. The amphibious capability of aircraft is particularly crucial for Türkiye’s geographical and climatic conditions, given the country's diverse terrain and numerous water bodies. Within these main criteria, sub-criteria such as engine power, aerodynamic characteristics, and refill capability play critical roles in influencing the rankings of the aircraft. Firefighting pilots and other experts provided essential insights through surveys, ensuring that the evaluation reflects practical and operational considerations. Their expertise was vital in accurately weighting the criteria and sub-criteria, enhancing the reliability and applicability of the study's findings.

The study concludes that the Canadair CL-415 and Air Tractor "Fire Boss" are the best-suited aircraft models for forest firefighting in Türkiye. These models excel in key performance areas and offer significant operational flexibility, making them highly effective for Türkiye's specific wildfire management needs. The proposed MCDM approach demonstrates robust adaptability for similar studies in other countries. This method provides a comprehensive framework for evaluating and selecting aircraft based on specific geographical and climatic conditions. Countries can modify the criteria and sub-criteria to suit their unique needs and constraints, ensuring that the approach is relevant and effective for different contexts.

7.2 Recommendations

Based on the study titled Multi Criteria Decision Making Approach for the Best Aircraft Model Selection for Forest Firefighting in Türkiye several key recommendations are proposed to enhance firefighting operations in Türkiye. The study emphasizes prioritizing the procurement of the Canadair CL-415 due to its superior aerodynamic characteristics, which offer excellent maneuverability and operational flexibility in diverse scenarios, including low-altitude and slow-speed capabilities for effective wildfire suppression in varied weather conditions. Regular training for pilots and strong collaboration with stakeholders, including public and private aerial contractors, are also deemed crucial.

Türkiye should optimize its firefighting fleet by incorporating a mix of top-ranked aircraft models, such as the Canadair CL-415, Air Tractor "Fire Boss," and Beriev Be-200. This strategic combination ensures a balance between initial attack capabilities and sustained firefighting efforts, enhancing overall effectiveness and response times. Additionally, integrating UAVs and drones into firefighting missions can significantly improve situational awareness, enabling real-time monitoring and rapid response, minimizing human risk, and providing precise targeting of fire hotspots. Drones equipped with thermal imaging and other advanced sensors can further enhance the accuracy and efficiency of firefighting operations. Exploring the modification of existing manned aircraft, such as the CL-415 and Air Tractor "Fire Boss," into unmanned versions could enhance operational safety and efficiency even further. This conversion would reduce the risk to pilots, allowing for more aggressive and prolonged firefighting strategies, particularly in hazardous conditions.

Future research should continue to apply the MCDM approach for evaluating new aircraft models and emerging technologies. Additionally, studies should explore the integration of UAVs and drones in greater detail, assessing their impact on overall firefighting effectiveness and their potential to complement traditional manned aircraft. Other countries can adapt the proposed MCDM framework to their specific needs, creating customized approaches that address local geographic, climatic, and operational challenges. This flexibility ensures that the best possible aircraft models are selected for each unique context, thereby enhancing the global effectiveness of wildfire management practices. The adaptability of the MCDM approach allows for its application in various regions, ensuring that localized conditions and requirements are adequately addressed.

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APPENDICES

Appendix A: Approval Of The Ethics Committee

T.C.
TÜRK HAVA KURUMU ÜNİVERSİTESİ
Etik Kurulu

Sayı : E-63878715-050-40255 07.06.2024
Konu : Etik Kurul İzni

DAĞITIM YERLERİNE

Üniversitemiz İşletme Fakültesi bünyesinde görev yapmakta olan **Dr. Öğr. Üyesi Meriç Hatice GÖKDALAY**, 30.05.2024 tarihli ve 28331 kurum sayılı dilekçesinde "**The Best Aircraft Model Selection for Forest Firefighting: "Case Study: Türkiye"** / **Orman Yangın Söndürme için En İyi Uçak Modeli Seçimi: "Türkiye Örneği"**" başlıklı yüksek lisans tez çalışması için hazırlamış olduğu Aydınlatılmış Onam Formu, Çalışma Protokolü ve Veri Toplama Formunun Üniversitemiz Etik Kurulu tarafından etik açıdan değerlendirilmesini talep etmiştir. İlgili belgeler Türk Hava Kurumu Üniversitesi Etik Kurulunun **03.06.2024** tarihli toplantısında incelenmiş olup etik açıdan uygun bulunmuştur.

Bilgilerinizi ve gereğini rica ederim.

Prof. Dr. Rahmi ER
Rektör

Ek: Dr. Öğr. Üyesi Meriç Hatice GÖKDALAY'ın 30.05.2024 tarihli ve 28331 kurum dilekçesi

Dağıtım:
Gereği:
İLGİLİ MAKAMA

Bilgi:
İşletme Fakültesi Dekanlığına
Sayın Dr. Öğr. Üyesi Meriç Hatice GÖKDALAY

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Appendix B: Data Collection Form

Multi Criteria Decision Making Approach the Best Aircraft Model Selection for Forest Firefighting in Turkiye

The purpose of this study is to select the most suitable aircraft model for combating forest fires in Türkiye, ensuring more efficient and effective firefighting operations based on predetermined criteria.

This survey is part of the thesis work of Master's Student Robert MUTABARUKA under the supervision of Dr. Meriç Gökdalay, a Faculty Member in the Department of Aviation Management at Turkish Aeronautical Association University.

When evaluating the criteria and aircraft, consideration should be given to the geography of Türkiye.

The names of the decision-makers evaluating the aircraft will remain confidential in this study.

In this study:

Criteria: There are 3 main criteria and 7 sub-criteria.

Alternatives (Evaluated Aircraft Models): 5 fixed-wing aircraft models are considered.

We greatly appreciate your support in this study.

Advisor: Dr.Öğr.ÜyesiMeriç Gökdalay
Department of Aviation Management, Turkish Aeronautical Association University
Tel:

Student: Robert Mutabaruka

Master’s Student, Department of Aviation Management, Turkish Aeronautical Association University

B.1 PAIRWISE COMPARISON DATA FORM

Pairwise Comparison OF Main Criteria For The best aircraft model selection for forest firefighting

Evaluation of Criteria for MCDM Approach for the Best Aircraft Model Selection for forest firefighting IN TURKIYE.

With respect to **the best aircraft model selection for forest firefighting**, which criterion is more important, and how much more on a scale 1 to 5? Please do the pairwise comparison of all criteria.

Numbers	1	2	3	4	5
Scale	Equal Important	Moderate important	Strong important	Very strong important	Extreme important

A or B, Which is more important and Kindly write your choice?				**By rating your choice with the scale 1 to 5? How much is important or more?**				
	A	**B**	**CHOICE**	1	2	3	4	5
1	Technical Performance	Hourly Operating Cost						
2	Technical Performance	Purpose-built						
3	Hourly Operating Cost	Purpose-built						

Pairwise Comparison Technical Performance

With respect to **Technical Performance**, which criterion is more important, and how much more on a scale 1 to 5? Please do the pairwise comparison of all Sub-criteria.

Numbers	1	2	3	4	5
Scale	Equal Important	Moderate important	Strong important	Very strong important	Extreme important

A or B, Which is more important and Kindly write your choice?				**By rating your choice with the scale 1 to 5? How much is important or more?**				
	A	**B**	**CHOICE**	1	2	3	4	5
1	Flight Duration	Water Tank Capacity						
2	Flight Duration	The aerodynamic characteristic						
3	Flight Duration	Engine power						
4	Flight Duration	Refill						
5	Water Tank Capacity	The aerodynamic characteristic						
6	Water Tank Capacity	Engine power						
7	Water Tank Capacity	Refill						
8	The aerodynamic characteristic	Engine power						
9	The aerodynamic characteristic	Refill						
10	Engine power	Refill						

Pairwise Comparison Purpose-built

With respect to “**Purpose-built (Structure)”**, which criterion is more important, and how much more on a scale 1 to 5? Please do the pairwise comparison of all Sub-criteria.

Numbers	1	2	3	4	5
Scale	Equal Important	Moderate important	Strong important	Very strong important	Extreme important

A or B, Which is more important and Kindly write your choice?				**By rating your choice with the scale 1 to 5? How much is important or more?**				
	A	**B**	**CHOICE**	**1**	**2**	**3**	**4**	**5**
1	Amphibious	Retrofit						

B.2 EVALUATION FORM

For The best aircraft model selection for forest firefighting using TOPSIS and MOORA Method

EXPLANATIONS OF THE CRITERIA

MAIN CRITERIA	SUB-CRITERIA	EXPLANATION
C_1		**TECHNICAL PERFORMANCE**
	C_{11}	**FLIGHT DURATION:** KNOWN AS "AIRTIME" REFERS TO THE PERIOD DURING WHICH AN AIRCRAFT REMAINS AIRBORNE FROM THE MOMENT IT TAKES OFF UNTIL THE MOMENT IT LANDS. THIS DURATION IS TYPICALLY MEASURED IN HOURS, MINUTES, AND SECONDS.
	C_{12}	**WATER TANK CAPACITY**: CARRY WATER OR FIRE RETARDANT FOR EFFECTIVE FIREFIGHTING.
	C_{13}	**AERODYNAMIC CHARACTERISTICS- TACTICAL CAPABILITY:** INFLUENCES **MANEUVERABILITY** WHICH GIVES THE ABILITY TO OPERATE IN DIVERSE SCENARIOS AND ENVIRONMENTS, LOW-ALTITUDE AND SLOW-SPEED CAPABILITIES WHICH IMPACT WILDFIRE SUPPRESSION EFFECTIVELY, TO HANDLE VARYING TERRAIN AND WEATHER CONDITIONS AS WELL AS ABILITY TO ACCESS CHALLENGING AREAS WITH WILDFIRES. OPERATIONAL FLEXIBILITY CONDITIONS AS A CRITICAL ASPECT OF AIRCRAFT PERFORMANCE TO OPERATE IN A VARIETY OF ENVIRONMENTAL CONDITIONS AND IN DIFFERENT TYPES OF AIRSPACE.
	C_{14}	**ENGINE POWER-TURBOPROP OR TURBOFAN JET ENGINES**: PROPULSIVE FORCE GENERATION AND EFFICIENCY. **TURBOPROPS** WITH THEIR STOL CAPABILITIES, FUEL EFFICIENCY AT LOWER SPEEDS, AND BETTER MANEUVERABILITY IN RUGGED TERRAIN, WHICH IS CONDUCIVE TO PRECISION IN FIREFIGHTING OPERATIONS. **TURBOFANS** WITH THEIR HIGH SPEED, WHICH IS BENEFICIAL FOR COVERING LARGE DISTANCES QUICKLY, HEAVY LIFT CAPABILITIES WHICH

		IS UNABLE AIRCRAFT TO CARRY MASSIVE AMOUNTS OF WATER/RETARDANT A FACTOR THAT COULD BE SIGNIFICANT IN A COUNTRY THE SIZE OF TÜRKIYE WITH POTENTIALLY WIDESPREAD FIRE ZONES.
	C_{15}	**REFILL**: CAPABILITY OF MAKING "SCOOPS" IN WATER QUICKLY (TIME). OR TURNAROUND TIME: THE QUICKNESS IN REFUELING AND RELOADING TO RETURN TO FIRE ZONES
C_2		**HOURLY OPERATING COST**
		HOURLY OPERATING COST WILL INCLUDE HOURLY FUEL CONSUMPTION COST HOURLY MAINTENANCE COST, HOURLY LABOR COST
C_3		**PURPOSE-BUILT (STRUCTURE)**
	C_{31}	**AMPHIBIOUS**: AIRCRAFT TYPE SKIMMING OVER A WATER SURFACE OR WATER FLOATS WHICH MEANS TAKE OFF/LANDING ON BOTH WATER AND LAND SPECIFICALLY MANUFACTURED FOR FIREFIGHTING.
	$C3_2$	**RETROFIT**: CONVERTED FOR FIREFIGHTING PURPOSES AND USE LAND WHILE TAKING OFF/LANDING.

THE FIREFIGHTING AIRCRAFT IN THE MODEL

FIXED-WING AIRCRAFT			
S/N	**AIRCRAFT MODEL**	**CATEGORY**	**COUNTRIES**
1	CANADAIR CL-215	MEDIUM: AERIAL FIREFIGHTING, SEARCH AND RESCUE, CARGO TRANSPORT	TÜRKIYE, SPAIN, CANADA
2	CANADAIR CL-415	MEDIUM: AERIAL FIREFIGHTING, SEARCH AND RESCUE, PATROL	TÜRKIYE, SPAIN, ITALY, GREECE, CANADA
3	AIR TRACTOR "FIRE BOSS"	LIGHT: RAPID, REPEATED ATTACKS ON WILDFIRES, INITIAL STAGES	TÜRKIYE, CANADA

4	LOCKHEED C-130 HERCULES	MEDIUM: AERIAL FIREFIGHTING, RAPID RESPONSE IN REMOTE AREAS	TÜRKIYE, CANADA
5	BERIEV BE-200	MEDIUM: AERIAL FIREFIGHTING IN DIVERSE ENVIRONMENTS	ITALY, GREECE, RUSSIA

TECHNICAL PERFORMANCE

When you consider TECHNICAL PERFORMANCE FACTORS, Please evaluate the Aircraft Models in the Table below and give scores according to the Score Table.

Technical Performance Sub-Criteria	Very Good	Good	Medium	Bad	Very Bad
Points	5	4	3	2	1

DECISION VARIABLES	**ENGINE POWER**	**SCORE**	**AERODYNAMIC CHARACTERISTICS**
CANADAIR CL-215	2-TURBOPROP ENGINES		
CANADAIR CL-415	2-TURBOPROP ENGINES		
AIR TRACTOR "FIRE BOSS"	TURBOPROP SINGLE-ENGINE		
LOCKHEED C-130 HERCULES	4-TURBOPROP ENGINES		
BERIEV BE-200	2-TURBOFAN ENGINES		

PURPOSE-BUILT (STRUCTURE)

When you consider PURPOSE-BUILT (STRUCTURE) FACTORS, Please evaluate the Aircraft Models in the Table below and give scores according to the Score Table.

Purpose-built Sub-Criteria	Very Good	Good	Medium	Bad	Very Bad
Points	5	4	3	2	1

AIRCRAFTS	**EXPLANATION**	**SCORE**
CANADAIR CL-215	SCOOPING WATER FROM SEA OR LAKES/RESERVOIRS, AMPHIBIOUS DESIGN / 2-TURBOPROP ENGINES	
CANADAIR CL-415	AMPHIBIOUS/ IMPROVED ENGINES, INCREASED WATER CAPACITY, BETTER AVIONICS/ 2-TURBOPROP ENGINES	
AIR TRACTOR "FIRE BOSS"	AMPHIBIOUS: RAPID REFILLING CAPABILITY, AGILITY & TURBOPROP SINGLE-ENGINE	
LOCKHEED C-130 HERCULES	MAFF SYSTEM-EQUIPPED, VERSATILITY, ABILITY TO OPERATE FROM SHORT ROUGH AIRSTRIPS. & 4-TURBOPROP ENGINES	
BERIEV BE-200	AMPHIBIOUS: T-TAILED DESIGN, ABILITY TO SCOOP WATER WHILE SKIMMING, VERSATILITY / 2-TURBOFAN ENGINES	

Appendix C: PCM With Online Software Tool for the AHP-OS

1. First Decision Maker

Main criteria

Consistency Ratio CR: 0.0%

Cat		Priority	Rank
1	Technical Performance	20.0%	2
2	Hourly Operational Cost	20.0%	2
3	Purpose Built	60.0%	1

Aggregation of individual judgments for 1 Participant(s)

	1	2	3
1	1	1.00	0.33
2	1.00	1	0.33
3	3.00	3.00	1

Technical Performance

Consistency Ratio CR: 6.7%

Cat		Priority	Rank
1	Flight Duration	13.3%	4
2	Water Tanker Capacity	22.6%	3
3	Aerodynamic characteristics	29.2%	2
4	Engine Power	30.1%	1
5	Refill	4.9%	5

Aggregation of individual judgments for 1 Participant(s)

	1	2	3	4	5
1	1	1.00	0.25	0.25	4.00
2	1.00	1	1.00	1.00	5.00
3	4.00	1.00	1	1.00	4.00
4	4.00	1.00	1.00	1	5.00
5	0.25	0.20	0.25	0.20	1

Purpose-Built

Consistency Ratio CR: 0.0%

Cat		Priority	Rank
1	Amphibious	83.3%	1
2	Retrofit	16.7%	2

Aggregation of individual judgments for 1 Participant(s)

	1	2
1	1	5.00
2	0.20	1

2. *Second Decision Maker*

Main criteria

Consistency Ratio CR: 0.0%

	Cat	Priority	Rank
1	Technical Performance	44.4%	1
2	Hourly Operational Cost	11.1%	3
3	Purpose Built	44.4%	1

Aggregation of individual judgments for 1 Participant(s)

	1	2	3
1	1	4.00	1.00
2	0.25	1	0.25
3	1.00	4.00	1

Technical Performance

Consistency Ratio CR: 6.6%

	Cat	Priority	Rank
1	Flight Duration	26.0%	3
2	Water Tanker Capacity	29.8%	1
3	Aerodynamic characteristics	10.0%	4
4	Engine Power	29.8%	1
5	Refill	4.4%	5

Aggregation of individual judgments for 1 Participant(s)

	1	2	3	4	5
1	1	1.00	3.00	1.00	5.00
2	1.00	1	5.00	1.00	5.00
3	0.33	0.20	1	0.20	5.00
4	1.00	1.00	5.00	1	5.00
5	0.20	0.20	0.20	0.20	1

Purpose-Built

Consistency Ratio CR: 0.0%

	Cat	Priority	Rank
1	Amphibious	80.0%	1
2	Retrofit	20.0%	2

Aggregation of individual judgments for 1 Participant(s)

	1	2
1	1	4.00
2	0.25	1

3. Third Decision Maker

Main criteria

Consistency Ratio CR: 5.6%

	Cat	Priority	Rank
1	Technical Performance	32.7%	2
2	Hourly Operational Cost	26.0%	3
3	Purpose Built	41.3%	1

Aggregation of individual judgments for 1 Participant(s)

	1	2	3
1	1	1.00	1.00
2	1.00	1	0.50
3	1.00	2.00	1

Technical Performance

Consistency Ratio CR: 3.4%

	Cat	Priority	Rank
1	Flight Duration	30.0%	1
2	Water Tanker Capacity	18.8%	4
3	Aerodynamic characteristics	22.7%	2
4	Engine Power	22.7%	2
5	Refill	5.7%	5

Aggregation of individual judgments for 1 Participant(s)

	1	2	3	4	5
1	1	3.00	1.00	1.00	4.00
2	0.33	1	1.00	1.00	4.00
3	1.00	1.00	1	1.00	4.00
4	1.00	1.00	1.00	1	4.00
5	0.25	0.25	0.25	0.25	1

Purpose-Built

Consistency Ratio CR: 0.0%

	Cat	Priority	Rank
1	Amphibious	80.0%	1
2	Retrofit	20.0%	2

Aggregation of individual judgments for 1 Participant(s)

	1	2
1	1	4.00
2	0.25	1

4. *Fourth Decision Maker*

Main criteria

Consistency Ratio CR: 4.0%

	Cat	Priority	Rank
1	Technical Performance	25.8%	2
2	Hourly Operational Cost	10.5%	3
3	Purpose Built	63.7%	1

Aggregation of individual judgments for 1 Participant(s)

	1	2	3
1	1	3.00	0.33
2	0.33	1	0.20
3	3.00	5.00	1

Technical Performance

Consistency Ratio CR: 8.6%

	Cat	Priority	Rank
1	Flight Duration	6.2%	5
2	Water Tanker Capacity	9.0%	4
3	Aerodynamic characteristics	28.7%	2
4	Engine Power	17.9%	3
5	Refill	38.2%	1

Aggregation of individual judgments for 1 Participant(s)

	1	2	3	4	5
1	1	1.00	0.25	0.20	0.20
2	1.00	1	0.20	1.00	0.25
3	4.00	5.00	1	1.00	1.00
4	5.00	1.00	1.00	1	0.25
5	5.00	4.00	1.00	4.00	1

Purpose-Built

Consistency Ratio CR: 0.0%

	Cat	Priority	Rank
1	Amphibious	83.3%	1
2	Retrofit	16.7%	2

Aggregation of individual judgments for 1 Participant(s)

	1	2
1	1	5.00
2	0.20	1