FEBRUARY 2020 M.Sc. in Industrial Engineering METEHAN ATAY

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GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

DESIGNING DOMESTIC FLIGHT NETWORK DEPENDING AIRCRAFT TYPE AND HUB LOCATIONS IN TURKEY

M.Sc. THESIS

IN

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BY

METEHAN ATAY

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M.Sc. Thesis

in

Industrial Engineering

Gaziantep University

Supervisor

Prof. Dr. Serap ULUSAM SEÇKİNER

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by

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Metehan ATAY

ABSTRACT

DESIGNING DOMESTIC FLIGHT NETWORK DEPENDING AIRCRAFT TYPE AND HUB LOCATIONS IN TURKEY

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Models developed on Hub location problems and collect-distributive network structures have been used extensively for the last 20 years especially in transportation and telecommunication fields. In this network, a centrally located facility serves as the main distribution base (Hub). Flows from other facilities are collected and grouped in the hub. This centralization and expansion of the operational network bring the advantage of economies of scale. In terms of airline companies, the flight network in the form of a distributor increases the profit of airline companies and provides significant savings in costs. In this study, it is aimed to give a new dimension to hub location problems. The effects of aircraft types characteristics on hub locations were investigated. Aircraft selection progressed by using five different multi criteria decision making methods based on the performances of airplanes and characteristics of air transport. Then mixed integer linear models for multi-assignment p-median hub problem and for flight legs and routes have been developed. Models were coded using GAMS 24.1 licensed software and CPLEX solver was used to solve multi-assignment p-hub median problem. It was concluded that the constraints and parameters used in the models had a significant effect on hub site selection and assignment. In addition, flight networks have been designed under different scenarios. It has been shown that the developed models can be used in the solution of the problem of determining the most suitable aircraft according to the different flight routes of the airline companies.

Key Words: Airline, Optimization, Flight, Network, Design, Aircraft, Selection

ÖZET

TÜRKIYE'DE UÇAK TİPİ VE HUB KONUMLARINA BAĞLI OLARAK İÇ HAT UÇUŞ AĞININ TASARLANMASI

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174 sayfa

Hub lokasyonu problemleri ve toplu dağıtım ağı yapıları için geliştirilen modeller, özellikle lojistik ve telekomünikasyon alanlarında yoğun bir ilgi görmekte ve kullanılmaktadır. Temel olarak ağ içerisinde, merkezi bir konumda bulunan tesis ana dağıtım üssü (Hub) olarak hizmet eder. Diğer tesislerden gelen akışlar merkezde toplanır ve gruplanır. Operasyonel ağın bu şekilde merkezileşmesi ve genişlemesi ölçek ekonomilerinin avantajlarından da yararlanılmasını sağlar. Havayolu şirketleri açısından, topla dağıt şeklindeki uçuş ağı, havayolu şirketlerinin kârını arttırmakta ve maliyetlerde önemli tasarruflar sağlamaktadır. Bu çalışmada, hub lokasyonu problemlerine yeni bir boyut kazandırılması amaçlanmıştır. Uçak tipleri özelliklerinin hub lokasyonları üzerindeki etkileri araştırılmıştır. Uçakların performansına ve hava taşımacılığının özelliklerine bağlı olarak beş farklı çok kriterli karar verme metodu kullanılarak uçak seçimi gerçekleştirilmiştir.. Daha sonra çoklu atama p-median hub problemi ve uçuş ayakları ve rotaları için karışık tamsayılı doğrusal modeller geliştirilmiştir. Modeller Lisanslı GAMS 24.1 yazılımı kullanılarak kodlanmış ve çoklu atama p-hub medyan problemini çözmek için CPLEX çözücüsü kullanılmıştır. Modellerde kullanılan kısıtların ve katsayıların hub lokasyon seçimi üzerinde önemli bir etkisi olduğu sonucuna varılmıştır. Ayrıca, uçuş ağları farklı senaryolar altında tasarlanmıştır. Geliştirilen modellerin, havayolu şirketlerinin farklı yatırım planları için fizibilite niteliğinde olduğu gösterilmiştir.

Anahtar Kelimeler: Havayolu, Optimizasyon, Uçuş, Ağ, Tasarım, Uçak, Seçim

‘’Dedicated to my family and my lovely blue eyed wise man‘’

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N	Airports
T	Amount of passengers
n	Number of airports
i	Departure point
j	Arrival Point
k and l	Potential Hub points
$\mathbf{H_k}$	Assigned Hubs
$\mathbf{B^i_{kl}}$	Flow amount passing through Hubs k and l from the starting point i
$\mathbf{A^i_{lj}}$	Flow amount from the starting point i and passing through the Hub l to point j
$\mathbf{E_{ik}}$	Amount of flow from the starting point i to Hub k.
$\mathbf{I_k}$	Airport infrastructure cost
$\mathbf{F_k}$	Airport Facility restoration cost
$\mathbf{C_{ij}}$	Unit cost between i and j
dij	Distance between points i and j
$\mathbf{PT_{(month,k)}}$	passenger traffic on month k
R	Maximum range
$\mathbf{FL_i}$	Total flow rate out from node i
$\mathbf{FL_{ij}}$	Amount of flow from i to j
α,β,γ	Cost reduction coefficients (hub-hub, hub-node, node-hub)
$\mathbf{RL_1}$	Required length for take-off on standard atmospheric conditions at sea level(m)
$\mathbf{A_E}$	Altitude of the airport (m)
$\mathbf{TR_A}$	Airport reference temperature (°C)
$\mathbf{TS_A}$	Temperature of airport altitude under standard atmospheric conditions
$\mathbf{SR_L}$	Slope of Runway(%)
$\mathbf{RL_2}$	Required runway length adjusted for altitude (m)
$\mathbf{RL_3}$	Runway length adjusted for altitude and temperature (m)
$\mathbf{RL_4}$	Runway length adjusted for altitude, temperature and runway slope (m)
$\mathbf{S_i}$	Capacity of Hub airports

$\mathbf{D_j}$	Demand of node airports
$\mathbf{x_{ij}}$	Passenger flow from i to j
$\mathbf{P_k}$	Capacity of aircraft k
$\mathbf{D_{ij}}$	Distance between airport i to j
$\mathbf{Y_i}$	Number of passengers taken from airport i
$\mathbf{F_k}$	Fixed cost of aircraft k
$\mathbf{R_k}$	Cost per mile of aircraft k
$\boldsymbol{\theta}$	Earliest time to serve on airport i
$\boldsymbol{\varphi}$	Latest time to serve on airport i
$\boldsymbol{\varkappa}$	Average service time of airport i
$\mathbf{H_{ij}}$	Time needed between airport i to j
$\mathbf{M}$	Big number
$\mathbf{A^{i}_{jk}}$	Aircraft k assigned o route from i to j
$\mathbf{U_k}$	Aircraft k is used
$\boldsymbol{\omega_j}$	Arrival time of airport j
$\boldsymbol{\lambda}$	Arithmetic Mean

LIST OF ABBREVIATIONS

IATA	International Air Transportation Association
ICAO	International Civil Aviation Organization
SHGM	Directorate General of Civil Aviation of Turkey
DHMİ	General Directorate of State Airports Authority
TÜİK	Turkish Statistics Institute
ACI	Airports Council International
ERAA	European Regions Airline Association
MCDM	Multi-criteria Decision Making
GDP	Gross Domestic Product
ILO	International Labor Organization
CAI	Compagnia Aerea Italiana
CORSIA	Carbon Offset and Reduction Scheme for International Aviation
DM	Decision Maker
AHP	Analytic Hierarchy Process
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
ANP	Analytic Network process
ESM	Even Swaps Method
VIKOR	Vise Kriterijumska Optimizacija IKompromisno Resenje
DEMATEL	Decision-Making Trial And Evaluation Laboratory
ZOGP	Zero-One Goal Programming
FAHP	Fuzzy Analytic Hierarchy Process
LFPP	Logarithmic Fuzzy Preference Programming
NAIADE	Novel Approach to Imprecise Assessment and Decision Environments
ELECTRE	Elimination and Choice Translating Reality English
LCC	Low Cost Carrier
FCC	Full Cost Carrier
MTOW	Maximum Take Off Weight
ACMI	Aircraft, Crew, Maintanace, Insurance

AOA	Angle of Attack
MCAS	Maneuvering Characteristics Augmentation System
NEO	New Engine Option

CHAPTER 1

INTRODUCTION

In unceasing and changing environmental conditions, the world imposes on us necessity to use current conditions in the best way while bringing us to an environment in which we have to be kept pace. Since the existence of humanity, moving and transporting activity has presented many problems and workspace to us from past to present. As in every field of business, it is an important factor to follow and keep dynamic environment under control in the field of airline which is main way to transfer goods and passengers in these days. For this reason, optimization studies in airline industry under changing and developing environmental conditions has taken an undeniable place in the field of optimization. Under these circumstances, the International Air Transport Association (IATA) guides all these efforts, supports global standards for aviation, including aviation safety, flight safety, flight efficiency and sustainability, and provides manual data retention to keep dynamic environmental factors under control and provides resources for new studies.

Conditions that may vary from country to country have created new and different problems. These problems encouraged creative and innovative ideas and paved the way for platforms to put forward different ideas in the field of study. The pioneers operating in this platform which deals airline optimization problems are undoubtedly scientists and industrial engineers. Starting from this idea, necessity and importance of airline optimization studies can be clarified. Besides the acceleration of the amount of aviation activities in Turkey of industrial engineer capacity whose have high optimization skills that grows, is seen as the solution of problems. With the developments in recent years, Turkey is located among the top ten countries in the world in area of air transportation and is expected to make an even more important contribution to world air transportation both in domestic and international transit hubs in the coming years.

1.1 Motivation of Study

Transportation and mobility have gained great importance and became popular with the industrial revolution. Although the desire to discover new places that lasted for ages was made primarily by road, it was realized by sea and rail in later periods. The sky adventure, which began with the Wright brothers, has both fueled human desire to explore and produce, and is considered the beginning of a new era for both humanity and industries. Air transportation, which has been in a great development after the Second World War, has become a transportation sector which shows rapid technological and structural changes in a short time. Especially thanks to the speed it provides in transportation and cargo transportation is making significant progress.

Nowadays, people prefer airline transportation intensively while traveling and cargo transportation. The biggest factor in this is the time benefit and convenience provided by airline companies. Airline companies, time pressure to provide the fastest, reliable and comfortable service to passengers in a variable and dynamic environment, in complex business processes. The development of air transportation is of great importance for countries. The development of airlines is essential for tourism, trade and many other related industries. Airline industry in our country in recent years has entered into a major development trend. With the increase in the number of private airline companies.

However, the similarity of the aircraft fleets used and the low number of airlines limit the degree of the decrease in ticket prices and the services provided. It is possible to increase the amount of available seats and the transportation possibilities that can be offered to the passengers, and to create ticket and service conditions which is suitable for each budget can be create if the competition environment is exists. In this case, the necessity of a new and flexible airline whose priority can be established for domestic flights can be clearly stated.

In order to serve this purpose, it is planned to make a study by considering the different aircraft types besides the dominant brands seen when the fleets of the existing airlines are examined. The current market conditions and opportunities were examined and a lack of competition was identified and the idea of creating a fleet that could create a competitive environment and designing a flight service network emerged.

1.2 General Situation of Air Transportation in World

The liberalization trend in the air transport sector is spreading rapidly all over the world. As a result of the liberalization, globalization and commercialization tendencies, there has been a high demand for the supply created by the development of a variety of services in line with passenger needs and needs in air transport. The increase in per capita income worldwide and the development of interregional trade and tourism accelerated the growth in demand for the sector. Demand for air transport is increasing day by day in parallel with the worldwide economic growth.

When 2019 fiscal year is completed, IATA's 2019 annual review says that air transportation sector has increased global demand by %3.4 in cargo transportation worldwide. In addition, global air transportation capacity hold by IATA has increased its air transportation capacity rate by %5.4 more in the world [1]. In 2018, all airlines around the world achieved a cumulative net profit of $30 billion. The revenues of the air transport industry rose to $ 812 billion and 8% of the capital generated from the investment made [1]. It can be concluded that increase in amount of passengers accelerates work to be done in order to meet the demand changes and capacity changes. Airline optimization studies have been carried out in a wide range of areas, with a wide range of uses and important work to meet needs and create a solution base for possible future needs. Table 1.1 shows the annual passenger demand change in Turkey.

Table 1.1 Total worldwide passenger demand change in years [2]

Year	Demand	Year	Demand	Year	Demand
1970	1.866.157.152	**1987**	6.332.390.124	**2004**	14.266.064.126
1971	1.995.858.424	**1988**	6.694.185.472	**2005**	14.984.455.593
1972	1.834.850.740	**1989**	6.890.394.700	**2006**	15.910.166.070
1973	2.407.165.400	**1990**	7.182.804.396	**2007**	17.120.619.650

1974	2.876.067.000	**1991**	8.426.329.324	**2008**	17.281.662.823
1975	2.989.957.700	**1992**	8.631.817.652	**2009**	17.756.617.870
1976	3.280.818.376	**1993**	8.510.365.796	**2010**	21.202.852.414
1977	3.570.049.952	**1994**	9.159.107.624	**2011**	22.742.174.464
1978	4.001.245.024	**1995**	9.681.250.317	**2012**	23.862.561.129
1979	4.501.970.300	**1996**	10.293.667.924	**2013**	25.265.502.533
1980	4.504.846.728	**1997**	10.760.459.552	**2014**	26.869.041.900
1981	4.536.667.400	**1998**	10.835.281.280	**2015**	29.027.894.825
1982	4.644.810.148	**1999**	11.474.847.296	**2016**	31.142.618.505
1983	4.849.717.176	**2000**	12.279.297.869	**2017**	33.613.782.390
1984	5.169.548.928	**2001**	12.321.643.963	**2018**	36.047.773.501
1985	5.510.117.224	**2002**	12.120.523.171		

According to a study conducted by Boeing cover years of 2019-2038, worldwide economic growth rate is expected to be 2.7% annually on average, in parallel passenger traffic growth is 4.6% and fleet volume growth rate is to be 3.4% [3]. The place and share of regional air transport in these growth forecasts is considerable. In the study conducted by Boeing, considering the worldwide demand for commercial aircraft among the years of 2019-2038, it is estimated that there will be an increase in the demand of regional air jets by 9% and an increase of 10% or more in single-aisle aircraft type. These statistics show that regional air transport will grow much faster than the general growth in air transport in the world.

These changes, which seem likely to occur in the fleet of airlines exist is worldwide will lead to a number of changes in civil aviation values around the world undoubtedly. The importance of single-aisle jets emerges when it is thought that the flights made by medium and wide-bodied aircraft of the major airlines will be made in the future with more efficient and smaller aircrafts. The airplanes in the airline fleets that are actively used in the world are schematized according to the fuselage type in Figure 1.1.

Today's major airlines have faced economic problems due to increased costs including fuel, operating and crew costs and reduced revenues. In order to improve these disadvantages, the airline sector is turning to common code sharing, global alliances and low-cost regional transport which is an important part of the system. These markets, which are not suitable for single-aisle aircraft with a capacity of 150-200 seats, such as Airbus A320, A321, Boeing 737-800 which are used by medium airlines for medium range. But in the situation of short haul transportation, those types of aircrafts are nullifies the profit efficiency and cost effectiveness functions.

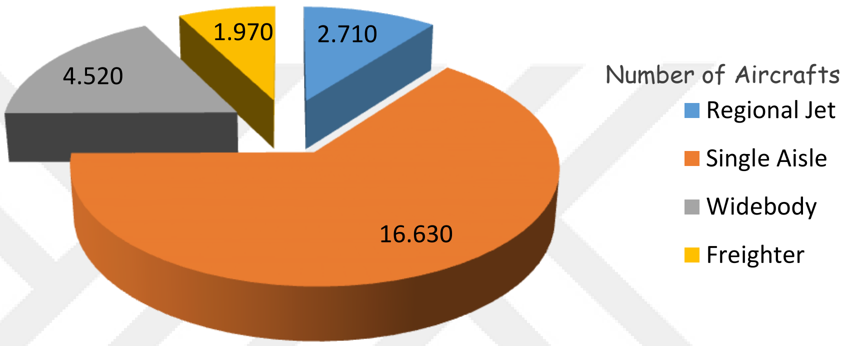


Figure 1.1 Distribution of aircrafts by it fuselage type in world [3]

In this case, as mentioned earlier, the trend towards aircraft fleet revision policy, which reduces passenger transport costs, increases profitability and reduces operating costs, is increasing day by day. This tendency will give rise to new or modified but known problems. Detailed analysis of the mentioned trends and the reasons of these types of tendency of policies will be the pioneers of absolute development.

1.3 Development and General Situation of Air Transportation in Turkey

Studies on aviation began in the period of Ottoman Empire limited to the military field. The Ottomans who were attacked by Italians in the Tripoli War understood the importance of aviation. Ottomans, who learned lessons from this attack, laid the foundation of Turkish civil aviation. In 1933, civil air transport was carried out under the name of Turkish Air Mail with a fleet of 5 aircraft. In the 10th Anniversary of the

Republic of Turkey, the State Administration of Airlines was established. This institution is authorized to carry out air transportation, to construct and operate airports and similar facilities.

The State Administration of Airlines, which successfully carried out these activities, later formed the cornerstones of Turkish Airlines. In these periods, not only the government but also the citizens had initiatives particularly. Nuri Demirağ is one of the people who have a large share in private enterprises. With his own venture and capital, he established aircraft and engine factory and aircraft assembly factories in Istanbul. Nuri Demirağ shown as a trailblazer in the aviation industry has been operating in Turkey. Nuri Demirağ built the first Turkish type passenger airplane with totally local engineers and workers. The Nu / D38 type passenger airliner was selected first in the category of "European Class A" passenger aircrafts in 1938. The actual development of civil aviation in Turkey began after World War 2. In this period, both modernization of airplanes and construction of new airports were emphasized.

When Turkish Civil aviation was examined between 1958 - 1983, Turkish Airlines (THY) was the only airline carrier in the country on national and international lines with a fleet of F27, Viscount, DC9, DC10, B707, B727 type aircraft initially. In this period, Turkish Airlines was not only providing passenger and transport services, but also providing catering services and customer services under another name which is called Çelebi Air Services. Since 1983, the laws adopted by the state have been in search of improvement, modernization and quality in aviation services. During this period, it was seen that Turkish Airlines started to develop its fleet within the framework of the modernization and standardization program, attempted to increase the service standards and directed towards economically advantageous international lines rather than domestic lines.

It is seen that airport investments are more focused on the improvement of existing standards rather than the construction of new conventional airports in the late 80's and early 90's. Meanwhile, investments aimed at increasing the quality and reliability of air traffic control, communication, navigation services, ground services and similar services have been continued. In 1998, the economic crisis in the Far East countries, the air transport sector in Turkey has also been negatively affected.

The air transport sector, which began to recover slowly in the early 2000’s, entered a narrow strait due to the economic crisis in 2001 and the terrorist acts in the US on September 11, 2001, causing dramatic reductions in passenger and aircraft traffic. According to the report of the International Civil Aviation Organization (ICAO) in 2003, scheduled airline companies, which closed 2002 with a loss, lost 0.9% of their operating income in 2003, which is also interpreted as the beginning of the revival in the sector. Number of passengers carried by scheduled airlines, which completed 2003 partially in development, increased compared to the previous year and seat occupancy rates reached 71% [4]. Constructive implementation of policies since 2003 by monitoring and preventive policies, 13 airline companies operating in the aviation sector in Turkey has grown rapidly. This growth has led to an increase in other Aviation businesses such as Maintenance and Training organizations and Ground Handling Organizations.

In the age of changing and developing global information and technology, time saving, comfort and convenience have become the reason of choice by people and therefore, with the developing technology, significant innovations in transportation sector have shown a simultaneous development with the development of human history. International borders and economic borders have lost their importance in the globalizing world and these developments have made airline transportation more attractive. In particular, many countries have invested heavily in this sector and have seen it as one of the criteria of being developed. When take a glance at the historical development of air transport and civil aviation industry in Turkey, it can be seen that has not been a country that has too much active. However, especially in the last decade, a significant improvement has been observed especially with the models preferred by the government in the field of airport investment and the private sector has made investments in the field of civil aviation.

Again, renewal of the aircraft fleet over the last decade due to air transport companies made private sector, increase in number of airports in Turkey and to increase the number of projects promoting the air transportation also shows the importance given to Turkey's air transportation. However, especially in the last decade, a significant improvement has been observed especially with the models preferred by the government to enlargement of airport network in the field of airport investment and the private sector investments in the field of civil aviation in Figure 1.2.

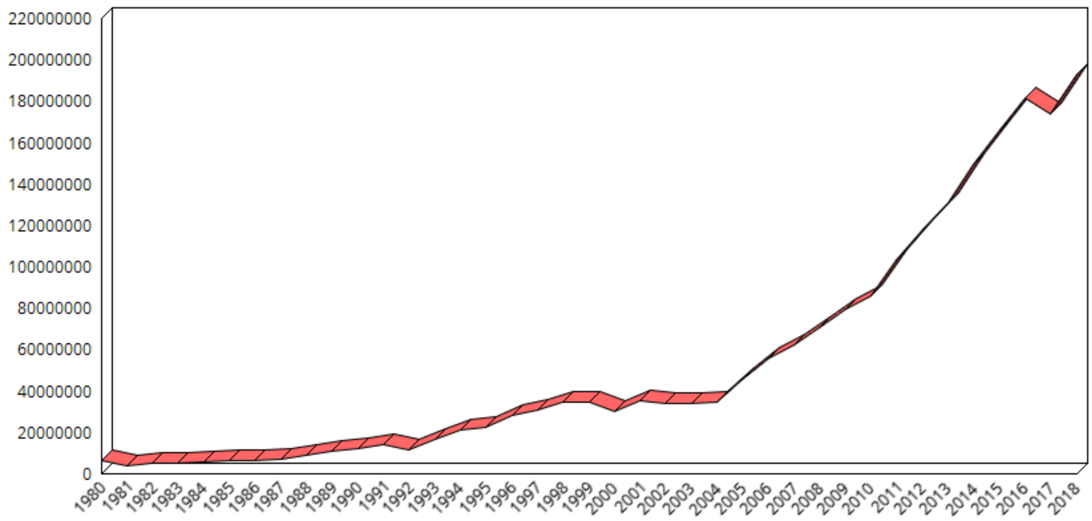


Figure 1.2 Roadmap of change on total airline passenger in Turkey

Again, renewal of the aircraft fleet over the last decade due to air transport companies made private sector, increase in number of airports in Turkey and to increase the number of projects promoting the air transportation also shows the importance given to Turkey's air transportation. If Turkey can give more importance to the air transportation sector with momentum that they caught, undoubtedly it will reach more important place to be able to become a leader among the European countries.

Table 1.2 Total airline passenger demand in Turkey

Year	Total Passenger	Year	Total Passenger	Year	Total Passenger
1979	5.935.276	**1993**	20.674.531	**2007**	70.352.867
1980	3.458.165	**1994**	22.334.286	**2008**	79.438.289
1981	4.641.772	**1995**	27.767.379	**2009**	85.508.508
1982	4.669.648	**1996**	30.780.662	**2010**	102.800.392
1983	5.387.791	**1997**	34.396.334	**2011**	117.620.469
1984	6.132.361	**1998**	34.199.679	**2012**	130.351.620
1985	6.323.448	**1999**	30.011.658	**2013**	149.430.421
1986	6.869.986	**2000**	34.972.534	**2014**	165.720.234
1987	8.903.699	**2001**	33.620.448	**2015**	181.074.531
1988	10.840.179	**2002**	33.755.452	**2016**	173.743.537
1989	11.843.563	**2003**	34.424.340	**2017**	193.045.343
1990	13.629.965	**2004**	45.034.589	**2018**	210.498.164

1991	11.019.464	**2005**	55.545.473	**2019**	228.742.365
1992	16.495.118	**2006**	61.684.203		

The development of air transport is of great importance for transportation sector of any country. The development of airlines is essential for tourism, trade and many other related industries. The airline industry has entered a major development trend in our country in recent years with the increase in the number of private airline companies shown in Table 1.2. Along with the increase in the number of airports serving in Turkey, it has become possible to reach more cities by air. In addition, with the dynamic pricing policies implemented, airline tickets can be bought and travel to similar prices with highway transport. It should not be forgotten that with the effect of competition, an improvement in prices will be observed for the passengers.

1.4 Domestic Air Transportation in Turkey

Despite all the political and economic problems in the world, air transportation increases its importance compared to other modes of transportation and passenger and cargo transportation continues to grow steadily. Aviation has become an important player in global development in all aspects. Developing countries have begun to come to the forefront as a result of the interest of the middle class in air transportation in the context of population increases above the average and economic developments. Axis shift from west to east continues in air transport activities. The impact of growth in Asian, Middle Eastern and African markets is increasing every year.

Geographically, between the three continents of Asia, Europe and Africa, which has a very important position in the middle of Turkey, it is located on the route between emerging markets and developed markets. Turkey, since 2003, put into practice in air transport operations with a liberal aviation policy has been one of the most progressive countries in the world. Istanbul has become one of the largest global transit centers in the world. It is certain that much more airplane and passenger traffic will be reached after the new airport commences service completely. Turkey's rapid rise in air transportation has slowed down among years 2015–2016 due to the political crisis and coup attempts as a cause. Later in 2017 it started to rise again. On the other hand, political crisis with the Russian Federation in particular about shot down of a fighter jet has led to major reductions in the transport of tourists to the Antalya region.

Turkey is an important crossroads in air transport. Turkey, takes attention of world about the number of passengers carried in domestic as well as in the international arena, developing and determined country on aviation sector.

Table 1.3 Change of air transportation passenger demand in Turkey

	Total Demand	% Change	Domestic Demand	%Change	International Demand	%Change
2003	34.424.340	-	9.128.124	-	25.296.216	-
2008	79.438.289	57	35.832.776	75	43.605.513	42
2013	149.430.421	47	76.148.526	53	73.281.895	40
2018	210.498.164	29	112.911.108	33	97.587.056	25

It is said that the developments in the aviation sector are mostly in parallel with the economic developments of the countries. This is because the aviation sector has a positive relationship with economic growth [5]. But there is an exception for Turkey. Turkey, the growth rate experienced in the aviation sector despite the surge in growth has always kept high.

As can be seen from the Table 1.3, air transportation demand in Turkey have made great leaps in each field and grown. The growth realized in domestic passengers was intense and the growth was not seen below 30% over the years. The biggest impact on this growth has been achieved by airlines operating for domestic lines in Turkey undoubtedly shown in Table 1.4.

Table 1.4 Development of domestic air transportation in Turkey [6]

	2003	2018	% Change
Seat Capacity	27.599	97.351	71,65
Aircrafts	162	515	68,54
Cargo Capacity (ton)	302.737	2.194.450	86,20
Domestic Routes	26	56	53,57
Domestic Traffic(Flight)	156.582	893.223	82,47

Personnel	65.000	205.000	68,29
Endorsement(Mn US $)	3,06	110,00	97,22

Civil aviation sector in Turkey, there are 11 airlines that serves for passengers and freight. The number of aircraft of the airline companies is 515 in 2018. 486 of these planes are passenger carriers and 29 are cargo planes. The total seat capacity of our airline fleet is 97,351 and the total cargo capacity of cargo aircraft is 2,194,450 kg. In 2003, domestic flights were carried out from 2 centers to 26 destinations and as of the end of 2018, 56 destinations were reached from 7 centers.

1.5 Structure of Thesis

The idea phase of this thesis has started since the beginning of my master's degree and started to be implemented as of June 2019. The thesis is planned to consist of 6 main chapters and these 6 chapters are explained in detail. Flowchart of thesis is shown in the Figure 1.3. While the thesis was created, the existing theses were examined and it was seen that the theses partially replicated each other in some aspects. The lack of innovative knowledge and strong imagination has given inspiration to this thesis.

Chapter 1 provides detailed information about the main structure and general form of the thesis. It provides comprehensive information about the thesis to readers with ideas. Also this section describes the current situation at the time the thesis was created and gives hints about the necessity of the thesis.

Chapter 2 explains the necessity of the thesis comprehensively. It explains and presents the reasons under the subheadings in detail with logical reasons when explaining these requirements. It describes both the internal dynamics and external effects of the current market. Second chapter explains customer behavior and current market status.

In Chapter 3, the literature review was carried out and similar studies are investigated. Text mining method was used to conduct these researches and it was supported by a case study. The literature review includes mathematical models and multi criteria decision making (MCDM) problems for the fleet selection problem. In addition, operational research methods for flight network design have been extensively investigated.

The selection of aircrafts for the formation of required fleet for new airline is planned in Chapter 4. Aircrafts considered in creation of fleet were selected from as wide a range as possible. Domestic airlines were examined in detail in worldwide. Aircrafts were examined extensively and fleet was selected by scientific methods using their official knowledge which accessed by official websites of producers.

Figure 1.3 Framework and flowchart of thesis

Chapter 5 explains flight network design process widely. Flight network was designed by using operational research tools for the fleet. While flight network were designing, it is assumed that this airline company will serve just for Republic of Turkey in domestic destinations. Studies which are done as guiding ones in this area have been used as a source and investigated.

Chapter 6 explains all the results and findings of the study. It sets out the concrete aims of the work that has been performed. This chapter discusses and questions unfulfilled goals. In this respect, it creates a source for future studies on the way of science. It will be able to offer feasibility for future studies, as it has not been done before.

Chapter 7 deals with the total contribution of thesis and discussion of missing or skipped part also total advantage and disadvantage of study.

1.6 Novel Contribution of Thesis

A systematic process was carried out while investigating the main subject and importance of the thesis. This systematic process was streamlined by using text mining. Text mining process, also referred as text data mining [7] or discovery of information from text databases [8], is generally referred to as the process of extracting interesting and important concepts or information from unstructured text documents. Required data is obtained from various databases and the process is carried out to obtain important information. In the light of these transactions, important issues, current trends or concept information about a topic can be accessed.

Text data mining methods were also used during the structuring of the thesis. Data needed was obtained through the Thomson Reuters - ISI Web of Science database. All texts, articles, conference proceedings, editor notes that may be related to the thesis were scanned and examined. In this way, hot topics have been discovered about airline optimization and a process has been carried out in line with the needs. At the end of the process, important issues and conceptual inferences were diagnosed. The most important issues on the agenda were airline network optimization and airline pricing policies. Airline network configuration or design and optimization process is known to be complex and difficult to proceed in all aspects. This process also has a constant impact on pricing policy determination and service design processes.

In carrying out all these operations, mathematical models and expert systems are used to reach a feasible also optimal solution which can be answer of our determined needs. Because flight network design and pricing policies are directly linked to the type of aircrafts to construct to fleet selected for flight, commonly used approaches are known as integrated. However, the establishment of an optimization model with integrated approaches requires a great deal of time and data. Therefore, prior to the realization of integrated approaches, the main objective is to achieve the essential and easy transportation objectives, which is one of the basic needs for developing and low income countries. This thesis was written to emphasize on developing countries which Turkey is a member of them, to be placed as a role taker among developed countries in light to get warned to the further development of the aviation industry of developing countries is a step that is considered important. Also it may provide precursors ideas for new aviation trends in the future.

Selection of airline optimization or airline problems and causes of it explained briefly in introduction part. Information about the general status of aviation in the World and in Turkey have been expressed and transferred to readers. If there are readers who do not have information about the subject, they are informed. In this entire process, the analysis can be made and in order to achieve the correct information, publications, annual and monthly reports, research projects of the civil aviation authority in the world and in Turkey were followed and examined carefully. The list of these authorities is shown below.

- International Air Transportation Association (IATA)
- International Civil Aviation Organization (ICAO)
- Directorate General of Civil Aviation of Turkey (SHGM)
- General Directorate of State Airports Authority (DHMİ)
- Turkish Statistics Institute (TÜİK)
- Civil Aviation Assembly of Turkey
- Airports Council International (ACI)
- European Regions Airline Association (ERAA)

When reports analyzed, reviewed the world situation and Turkey separately and the rest of the thesis is built on this basis. Turkey's place in the world of aviation is explained and is supported by statistics and Figures. Turkey's development and innovations in domestic and international transportation has shown and addressed as success. Main structure of the dissertation and its reasons are clearly shown and visualized. Finally, the contribution of the thesis to the literature is explained, its future expectations are mentioned and presented.

CHAPTER 2

SYSTEMATIC PROBLEM DESCRIPTION USING TEXT MINING: A CASE STUDY ON AIRLINE OPTIMIZATION STUDIES

This chapter explains the use of text mining approach in problem identification and literature review activities. The popularity of the problem idea used in the process of the thesis and its approaches in the academic environment was measured with an intelligent system and the suspicion of the problem was confirmed. Thus, the scope and determinants of the problem to be studied are drawn with more precise limits. Text mining, which is used as a useful and consistent method in order to make the thesis a useful source of information, has been studied with keywords that can cover all the related fields and the results have been revealed.

The data determined for use in the text mining method were obtained and refined through the Thomson Reuters - ISI Web of Science database. Data refining process is the process of extracting relevant data in the process of extracting meaningful information by using data obtained from the database for text mining. In this process, the following data were selected for use from the data obtained from the database; title, abstract, publication year, publication name, publication year, host of publication, publication country. In the study, some of the documents were omitted because of those are carry meaningless information partially which called as noise or manipulator. Such documents are like as editor notes, patent documents, conference papers, etc.

2.1 Introduction

In academic life, the most important feature that distinguishes scientists is their creative problem solving and decision-making ability. It is very important to be able to find solutions to all kinds of problems quickly and easily and to be able to identify and analyze the problem simultaneously. When people's creative thinking is revealed, the solving skills they develop in the face of problems always make them one step ahead. However, scientists sometimes lack the ability to diagnose and identify problems. For this reason, use of expert systems and artificial intelligence to diagnose these problems and identify problems is very common nowadays. These systems are used to gain preliminary information about the problem encountered, to interpret the data acquired and to provide agile and quick solutions frequently. Besides these functions, data usage of text mining for problem determination is becoming popular to extract meanings from unstructured or textual data into clear, countable intelligible information.

All these studies have undoubtedly contributed greatly to the field of air transport and management and have shed light on future work. For this reason, it is necessary to explore new trends that can yield results and contribute to our development and revenue growth. The aim of this study is to determine the direction and emerging trends of the studies also possible occasions that predicament appears in this area by examining more than 700 studies using the keywords of “airline” and “optimization” between 1975 and 2018.

Unfortunately, the publications before 1991 were not indexed in electronic database, therefore input was constructed including data from 1991 to 2018 (including both 1991 and 2018). Following Figure 2.1 shows the numbers of publications on each year starting from 1991.

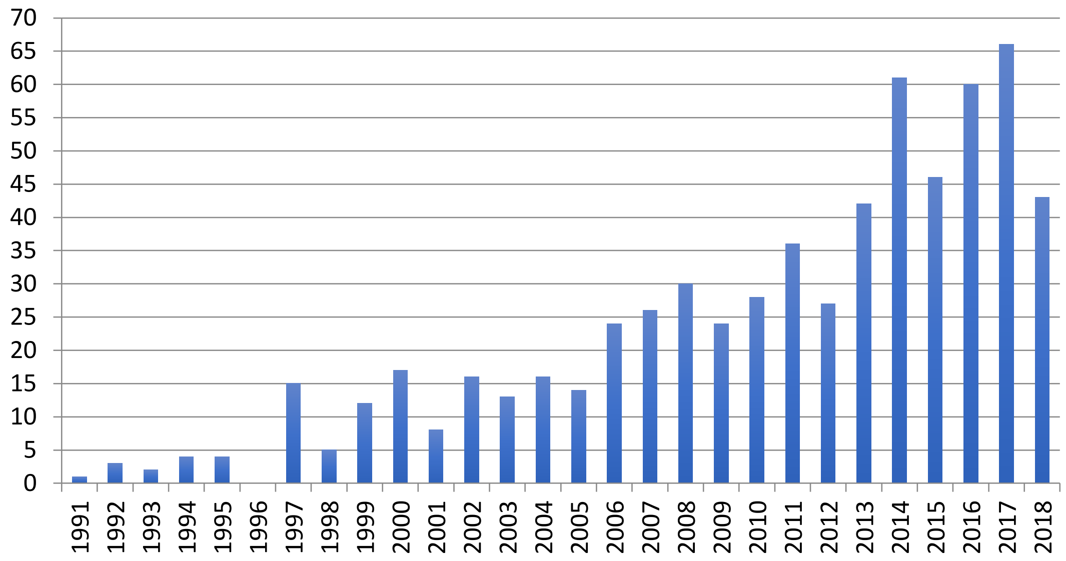


Figure 2.1 Published studies annually

Problem definition search was performed by scanning the studies conducted between 1975-2018 using Thomson Reuters – ISI Web of Science database. Since studies conducted before 1991 were not indexed electronically, literature range of the study was changed to between1991-2018 unfortunately. As can be seen from Figure 2.1 above, there is a noticeable increase in the number of studies after 2000 especially. The highest number of studies in Airline Optimization field was carried out with 229 studies by U.S and 118 studies by People Republic of China as second among 781 studies on all over the world until the end of the 2018 as shown in Table 2.1. It can be seen as a quick inference by bar chart in first sight, the most of the studies were carried out by developed countries in order to use of high technology and search of innovation.

Table 2.1 Country rankings on publications by 2018

Country	Number Of Publication	Percentage Of Total Publication (% Of 781)
USA	229	29,32
Chına	118	15,11
B**	63	8,07
A*	55	7,04
Germany	44	5,63
Taiwan	37	4,74
Turkey	31	3,97
Canada	30	3,84
France	24	3,07
England	22	2,82
India	19	2,43
Japan	16	2,05
Australia	15	1,92
Italia	13	1,66
Netherlands	12	1,54
South Korea	11	1,41
Spain	11	1,41
Sweden	11	1,41
Qatar	10	1,28
Singapore	10	1,28

***** : Countries That Have Less Than 5 Publications.***

****** Countries That Have Between 4 To 10 Publications.***

In order to prevent crowded images and to facilitate the transfer of information, countries with fewer publications were grouped in Table 2.2. Grouping criteria were established in two ways in order to ensure the reliability of the information. First group includes countries with fewer than 5 publications and second group consists of countries with more than 5 publications but not exceeding 10 publications. Countries within these groups are also explained as list.

Table 2.2 Country groups and members

0<x<5			4<x<10
Yugoslavia	Ethiopia	Latvia	Serbia
Wales	Cyprus	Croatia	Morocco
Ukraine	Belarus	Thailand	New Zealand
UAE	Azerbaijan	Malaysia	Iran
Poland	Scotland	Indonesia	Greece
Peru	Romania	Czech Republic	Brazil
Norway	Nigeria	Chile	Portugal
Kuwait	Mexico	Belgium	Denmark
Jordan	Kenya	Austria	Tunisia
Ireland	Israel		Switzerland

Also, it is crucial to know citations of those publications to gather information about publication quality and popularity. At the same time, change on number of citations in time can give idea about importance of working or study area.

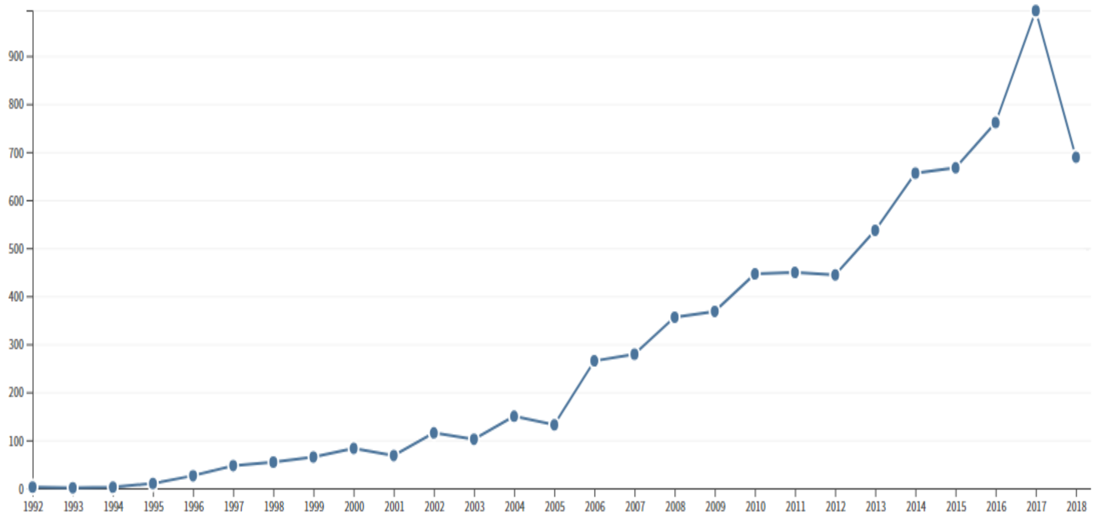


Figure 2.2 Change on number of citations

There has been a great improvement in the number of citations over the years shown in Figure 2.2. However, the decrease in the number of citations since 2017 is remarkable. It can be commented as decrease in popularity of those study area or repeating studies was published. Nevertheless, it may a change to get in the way of exploration to new problems and approaches. Nevertheless, it may an opportunity to get in the way of exploration to new problems and approaches. Thence, this smart problem definition tool can be concluded enormous amount of useful information.

2.2. Literature Review For Text Mining Tool in Problem Description

Since studies conducted before 1991 were not indexed electronically, literature range of the study was changed to range of 1991-2018 unfortunately. As can be seen from Figure 2 above, there is a noticeable increase in the number of studies after 2000 especially. The highest number of studies in Airline Optimization field was carried out with 229 studies by U.S and 118 studies by People Republic of China as second among 781 studies on all over the world until the end of the 2018 as shown in Table 2.1.

Knowledge discovery and data mining in databases has recently attracted the attention of a significant amount of researchers and industry professionals [9]. The vast majority of this interest comes from need to improvement of new methods that have brought us urgency of generating new information. Data analysis methods using known procedures are based on conventional methods or based on manual analyzes also illations which are person specific interpretations. Analysis of data within conventional ways is largely time-consuming, expensive and highly subjective, that’s why knowledge discovery and data mining techniques are needed. Text mining, which is one of the methods of data discovery, is a new tool that will help to eliminate these failures and save time and provide more concrete information. Technically, text mining is the use of self-inflicted methods for take use of enormous amount of knowledge available in text documents [10].

There are many areas in which text mining is used and contains a lot of unstructured information. Although text mining techniques vary widely, it is known that it provides useful information in areas where it is applied [11]. Business Intelligence, Bioinformatics or Pharmaceuticals and Energy are such areas that can be give as an example implementation of text mining techniques.

Moro, Cortez and Rita[12] investigated an analysis about business intelligence in banking on dirichlet allocation by using text mining. Kim, Ohta, Tateisi and Tsujii [13] was performed on a study about bioinformatics that aims to generate a system to provide reference materials to let nonlinear programming techniques study for bio-text mining. Also Eroglu and Seckiner [14] was used text mining techniques to identify trend topics and study clusters on the area of wind industry and wind energy.

Although the airline applications of text mining studies are not yet very common, it is possible to find some applications in some areas of text mining techniques. Most of these studies were carried out to determine customer behavior and use it as a means of information to develop some service systems to serve it. Liau and Tan[15] was investigated a survey about behavior of airline customer by using text mining on study of "*Gaining Customer Knowledge in Low Cost Airlines Through Text Mining*" study. This is one of those studies that done in airline sector and which has an impact in the field, has provided some methods by using the information obtained with text mining for low cost airlines to provide better service based on customer ideas. Härkänen et al. were put forward a sample project on the area of investigated factors contributing to nurse employees in drug administration violations [16]. The basic target of study were to explore the extent to which incident reports recorded personnel issues as contributors to drug administration incidents and was a pilot study and had striking results.

Thus, this study can be initial epitomizes of its own field that encapsulates studies heretofore and used as a feasibility tool to future airline optimization study literature as a whole and also be used as a monitor mechanism to discuss emerging trends in the field of study.

2.3 Text Mining Methodology

The main mission of text mining in this study, which is carried out with airline optimization studies, is to find the tendencies of the studies that have been done so far and to define the needs that can be undertaken in the future. While performing this study, the text miner extension of the STATISTICA 10 software trial version was used and all of the statistics were performed. On the other hand, use of software for text mining, preparation of some necessary data and some steps of text mining was carried out manually. Main steps of text mining are shown in Figure 2.3.

Figure 2.3 Main steps of text mining

While selecting database, comprehensive "*airline optimization*" searches are done in order to reach as many relevant researches as possible according to query that written. In order to shorten the work time and to make it easier to reach more precise information, searches were made in electronic databases. Thomson Reuters - ISI Web of Science database which used by many academicians and students worldwide has been selected for use in this study.

In order to reach qualified and relevant data as a result of query, all items except the articles and conference proceedings were eliminated in the search with keyword *"airline optimization"*. Only published articles and conference proceedings were reviewed and study area was narrowed down to reveal specific features of the study. While preparing the data, *topics* to be used in text mining were selected, the irrelevant ones were screened, multinational publications published in multiple countries were singled out and a data set was created and stored in an excel sheet. Data in the set are collected under the following headings; Journal Type: Journal(J) or Confrence Proceeding (P), Publication Year, Title, Author's Name, Country, Abstract, Published Language, Source. An example of data is shown on Table 2 below.

Table 2.3 Sample part of data stored

Type	**Year**	**Title**	**Authors**	**Country**	**Abstract**	**Source**
P	1997	Panel on transportation and logistics modeling	Carson, JS; Manivannan, MS; Brazier, M; Miller, E; Ratliff, HD	USA	Transportation and logistics are fertile areas for modeling. Simulation has traditionally	Proceedings Of The 1997 Winter Simulation Conference

					been used …	
J	1998	Priority pricing in air	Lenoir, N	France	Airspace congestion has..	Nouvelle Revue Aeron..

Data set was indexed and scanned using the text miner property of STATISTICA software. Anova analyze, which is required for the analysis, was also implemented with the same software via the statistics extension.

2.3.1 Data Gathering

The basic method used in Statistica Text and Document Mining will look for a list of documents containing text and index the unique words contained in those documents. Various input file formats are supported, including the currently used file types.

The abstracts of all available publications between 1991 and 2018 was obtained from the database and transferred to the excel file then created a spreadsheet. The database is constructed with the Publication type, Publication Year, Publication Title, Authors' name, Authors' country, Abstract, Language and Source. Irrelevant editorial notes, research notes, patents, news, and reviews are not selected for database to include only relevant studies.

While the publications were classified on country basis, those with less than five publications in that country were grouped and group A was classified as group B by clustering between 5 and 10. The data collected after the collection process is proper for text mining study.

2.3.2 Text Mining Process

Text mining is a set of operations using a text document as a data source to obtain valuable structural information. This process requires complex analytical tools that process text to collect the required keywords or overlooked or unprocessed key data points. Following steps have been meticulously completed shown in Figure 2.4;

Figure 2.4 Text mining process

- The database was created as excel spreadsheet and import into Statistica software as Statistica workbook spreadsheet.
- The Abstract section of the publications was selected as variable for the study from the database.
- The stemming language was determined in English and the word to be chosen was determined to be 3000 and the minimum frequency of word to be selected was 3%.
- Stop Words, Synonyms, and Phrases were defined so that the text mining study could proceed with rigorously.

The stop word list contains the words that will not be included in the analysis in the process (Ex. am, is, are, etc.) the Synonyms list contains the words that should not be evaluated separately (study, studies, prefer, preferences, etc.) and the Phrase list contains the words that should be evaluated as a single word. In addition to these words, the frequently used academic literature, such as airline, articles, flight, copyrights, Airbus, Boeing, etc. words have been added to the stop word list. If there were more than one word with the same meaning (Ex. tendency, inclination, trend), it became synonymous with the previous word by merging operation. Default Settings of word processing/filtering parameters of text mining was used in study.

After the processes described above, the indexing process can be started. There are many popular text retrieval indexing techniques similar to reverse indexes and signature files exists. The index method we use in this study indexes the variables defined in the database we use. Based on more than 700 articles, the total number of words selected was 847 and list of top 30 important words is given on Table 2.4.

Table 2.4 Importance of top 30 words

	Word	Importance		Word	Importance		Word	Importance
1	crew	100,00	11	price	75,50	21	route	65,70
2	delay	96,05	12	air	74,49	22	control	64,12
3	airport	88,24	13	disruption	71,12	23	class	62,92
4	recover	84,96	14	fuel	70,67	24	flight	62,55
5	rm	84,58	15	demand	70,48	25	capacity	61,88
6	maintain	83,65	16	network	69,71	26	gate	61,52
7	revenue	80,78	17	traffic	69,59	27	schedule	61,42
8	fleet	77,20	18	system	68,07	28	fare	61,27
9	emission	76,23	19	transport	66,70	29	operation	60,80
10	aircraft	76,04	20	pair	66,42	30	policy	60,60

Taking this information into consideration, it can be said that the researchers are mainly studying crew, airport and delay issues or dealing with related subjects. Mainly, those words are related with effects of delay on crew, revenue and airports.

Following the indexing process, the concept extraction process is started by using these documents and possible concepts are monitored. There are 4 common methods for concept extraction. These methods are;

A. *Raw Statistics;* Raw statistics are extract the amount of words in all documents.
B. *Binary Frequency;* If there is a word in a document, the frequency takes 1 else 0.
C. *Logarithmic frequency;* Various transformations of frequency counts can be realized and derived. The frequency of use of words or terms usually indicates how dominant or important a word is in a document. In particular, words that appear as high priority in the frequency count define the content of this document better. So Logarithmic Frequency computes frequency of a word in indexed database by using formula as given in Equation 2.1.

$$F = 1 + log(wrf) \quad \text{where} \quad wrf > 0 \tag{2.1}$$

Wrf is word raw frequency. Somehow, the frequency of use of words does not indicate the importance of the article. For example; Suppose a word is used so frequently in a study which means this word is important. If this word is used 5 times in X article, and used 3 times in article Y, it is not reasonable to say that X article is more important. For this reason, use logarithmic frequency is more suitable under this circumstance.

D. *Inverse Document Frequency;* This frequency is the relative frequency of different words. On the other hand, an important indices can be used in further analyses is the relative document frequencies (df) of different words. For example, a term such as "airport" may occur frequently in all documents, while another term such as "destination" may only occur in a few. A common and very suitable transformation that shows both the uniqueness of words (document frequencies) at the same time the overall frequencies of their occurrences (word frequencies) is called as inverse document frequency (for the ith word and jth document) as in Eq. 2.2:

$$idf(i,j) = \begin{cases} 0, \ if \ \ wfi = 0 \\ [(1 + \log(wfi))log\frac{N}{dfi}], \quad if \quad wfi \geq 1 \end{cases} \tag{2.2}$$

where;

N: Total number of documents.

w_f: Word frequency for whole documents

d_f: Word frequency for current document.

Inverse document frequency which is considered as the most effective tool for the reasons mentioned in this study was used. In the light of this method, concept extractions are made and shown in the Figure 2.5 below.

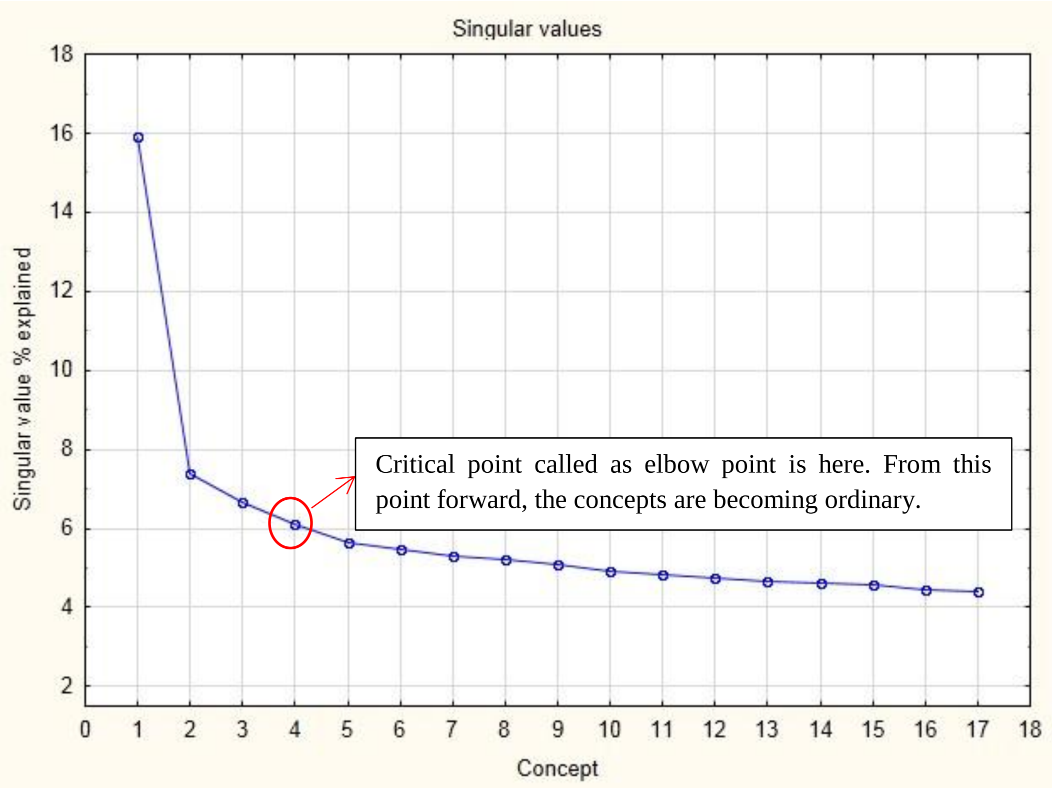


Figure 2.5 Plot of extracted concepts

Figure 2.5 gives the Scree Plot of extracted concepts that is used to decide on the number of singular values that are useful and informative, and that should be retained for subsequent analyses. Usually the number of "informative" dimensions to retain for subsequent analysis is determined by locating the "elbow" in this plot[14]. The points, which are above from elbow of the graph, have more importance than others[17]. In this study, there are 17 concepts. As you can see from Figure 4, the critical point called elbow point is on the 4th concept. Clustering techniques were applied to define clusters of similar documents, and Anova test was used to analyze the differences between the related procedures.

2.3.3 Results and Discussion

In this section, the data obtained from the studies and the inferences about the sector were interpreted and an important direction was determined for the future studies. The direction determined in this context has an important place in order to have a bigger share in the climate of change in the last years. The points and rankings of the concepts obtained following the processes of indexing and conceptualization are shown on Table 2.5 below. Based on this information, it was decided and examined which clustered concepts should be examined by looking at Table 2.5 . In this context, it was concluded that the first 4 concepts should be examined carefully. Although the first four concepts will be examined, all concepts and words are given in the Table 2.5 below.

Table 2.5 Sequenced concepts and imported word ranks

CONCEPT	1. Rank	2. Rank	3. Rank	4. Rank	5. Rank	6. Rank
C1	aircraft	flight	delay	operation	network	schedule
C2	revenue	price	rm	fare	demand	customer
C3	revenue	policy	fare	booking	class	seat
C4	rm	bus	items	factor	mode	business
C5	crew	side	user	period	would	pairing
C6	workloa	pilot	rm	ground	delay	weather
C7	fleet	pilot	design	market	decision	aviation
C8	recover	disruptio	maintain	support	center	control
C9	air	Multi	applicatio	airport	network	system
C10	disruptio	robust	market	itinerary	network	choice
C11	gate	total	fly	airport	security	rate
C12	emission	speed	price	co2	consumptio	carbon
C13	cargo	hold	industrial	rm	authors	airport
C14	itinerary	statistics	data	travel	carrier	pair
C15	dual	lp	program	integer	optimal	partitionin
C16	exist	cargo	capacity	co2	load	hub
C17	rm	departur	forecast	trajectory	step	support

The most important words for the concepts are shown above as in Table 2.5. The words are interpreted using this Table. As a result of the studies made from the Table, the meanings of the concepts are inferred shown in Table 2.6. Concept headings obtained from the inferences from the Tables do not have a definite meaning but give an idea about the subject.

Although all of the concepts shown are currently being worked on, the concepts Aircraft Operation Network Scheduling, Revenue and Price Management Revenue And Booking Fare Policy and Effects of Business Factors On Revenue Management are the most prominent ones and are also the most widely studied nowadays. If Table 2.4 and Table 2.5 are examined comparatively, it is seen that the most important words presented in the study are not the same as the most important words revealed by the concepts. In this context, it can be said that concepts are a more useful approach than to make sense of the words that are obtained in general. Although conceptual approaches are logical and useful, it can be seen that some concepts are not meaningful enough (Concept16, Concept14, Concept8 etc.). This meaninglessness does not change the course of the work seriously but it cannot help us to reveal some unknowns. These uncertainties may be terms such as the full content of the concept, the scope of the concept, and the like shown in Table2.6.

Table 2.6 Concepts and focusing area

CONCEPTS	FOCUS AREA
CONCEPT1	Aircraft Operation Network Scheduling
CONCEPT2	Revenue And Price Management
CONCEPT3	Revenue And Booking Fare Policy
CONCEPT4	Effects Of Business Factors On Revenue Management
CONCEPT5	Crew Pairing in a Period
CONCEPT6	Workloads Of Pilots On Revenue Management
CONCEPT7	Fleet Assignment and Pilot Decision
CONCEPT8	Maintaining And Recovering Operations
CONCEPT9	Multi-Objective Airline And Airport Network Operations
CONCEPT10	Robust Market Itinerary Choice
CONCEPT11	Airport Gate Assignment
CONCEPT12	Green Fleet Design
CONCEPT13	Cargo Airport Congestion Implications
CONCEPT14	Itinerary Statistics Data And Travel Carrier Pairing
CONCEPT15	Revenue Management On Dual Lp Program
CONCEPT16	Cargo Capacity Management On Hubs
CONCEPT17	Revenue Forecasting On Departure Trajectory

The most important concept which is Concept 1, is the subject that focuses the attention of the researchers. First concept consists of aircraft, flight, delay, operation, network, schedule, system words sequentially. It can be concluded as Aircraft Operation Network Scheduling. It is not surprising to study this subject under changing conditions every day.

Second important concept consists of revenue, price, rm, fare, demand, customer, control. This concept denoted as Revenue and Price Management. It may be surprising, however, that concepts 2 and 3 are examined as two separate issues because of the effect of the selected policy on the management cannot be rejected. Concepts after concept 4 have not been examined in detail because they are located after the elbow point which is an indicator of becoming ordinariness of subject as shown in Figure 2.5.

2.3.4 Important word clustering analysis

The text mining study indexed and produced more than 800 words under total of 17 concepts. Concepts and words are clustered and listed. Clustered words were evaluated by matching them with the concepts to which they belong. It was seen that the words contained in the concepts were not the same as the words set out in the total and were examined and interpreted. It was seen that the concepts listed as important included fewer and more meaningful words, and the number of words increased in the concepts that were considered insignificant. Clusters are shown in Figure 2.6 . In order to reach more accurate information and to provide more detailed examination, anova analysis is used. The confidence interval of the other concepts was found to be insignificant as it did not meet the 95% criteria and was not examined in this context.

Final classification	Value	Distance to centroid
1	157,3450	0,000000
2	72,8940	0,029897
2	66,0850	0,029897
4	60,4020	0,048059
4	55,9929	0,009340
4	54,1412	0,006921
4	52,4460	0,021806
4	51,6642	0,028672
3	50,3629	0,034018
3	48,4547	0,017261
3	47,9011	0,012400
3	46,9803	0,004314
3	46,2724	0,001903
3	45,8173	0,005899
3	45,1304	0,011931
3	44,0138	0,021736
3	43,4683	0,026526

Figure 2.6 Clusters of important words

It is clear that cluster 1 is more striking than the other clusters. Clustering score was determined as twice the nearest cluster. Therefore, the words in the first cluster have a significant difference and importance from the other words in another clusters.

Table 2.7 Top 8 words of first cluster

Cluster 1	
1 aircraft	5 fleet
2 network	6 crew
3 price	7 delay
4 operation	8 revenue

Comprehensive review of the words that belong to the most important concept is presented. When we look from the important to insignificant in the concept ranking, amount of words they contains are increased. However, the most important concept includes fewer and clear words which we can understand total section. For this reason Cluster 1 indicates problems about aircraft operation networks and revenue issues within considering crew of fleet shown in Table 2.7.

2.3.5 Analysis of Results with Anova

ANOVA performs hypothesis tests which say that some variables have the same average value in two or more populations. The procedure derives its name from an elegant chain of reasoning about variances to conclude that the mean values of the variable are the same. ANOVA technique was invented in the 1920s by a British mathematician Sir R. Aylmer Fisher. In this study, ANOVA technique was used to measure whether airline optimization study trends have changed significantly by year or country or not. All results which considered in study has p value less than 0,01 and confidence interval of 0,95.

The internal dynamics of the study with ANOVA analysis were investigated, and internal and external factors were investigated and analyzed. When performing ANOVA analysis, the confidence interval was 95%. Data that do not meet this confidence interval is considered meaningless and excluded from the study. When the publication year and concept relations are examined under these conditions, it has been seen that only Concept 1, Concept 5 and Concept 12 have developed meaningful relations over the years.

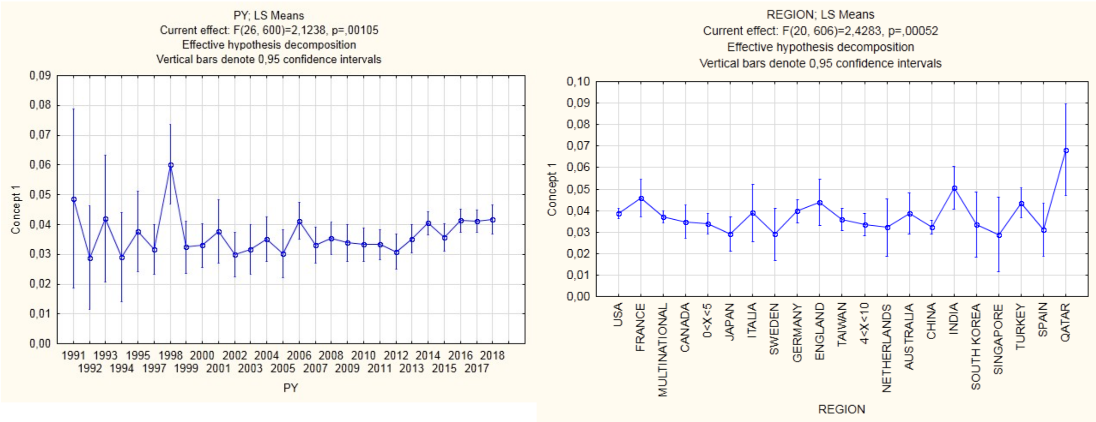


Figure 2.7 Anova for concept 1 vs. publication year/region

When Figure 2.7 is examined, it can be seen that Concept 1 has a fluctuating tendency over the years. It can be said that there was a great fluctuation especially between the years of 1991-2000 and after 2000 it became stationary and important. The majority of the studies carried out under this concept can be seen to be made by Qatar. The fact that Qatar gives so much importance to these studies explains the steps taken by Qatar in order to become a global airline as Qatar Airways.

The latest annual reports once again reflect the success of Qatar Airway's expansion and growth strategy that has seen the Qatar Airways Group grow from a small regional airline into an aviation powerhouse over the last two decades [18]. As can be seen from this point of view, it is an undeniable fact that Concept 1 is important for the development and globalization of an airline company. Besides Qatar, India, England, Italy and Turkey's "Aircraft Operation Network Scheduling" on where the work is seen.

Total seat capacity of the European aviation network has grown by 59% between 1990 and 1998. The growth of intercontinental traffic (73%) and intra-European traffic (77%) has both been above the 70%. Domestic traffic has increased by 37% over the same time period [19].

The growth of 73% in intercontinental traffic has justified and triggered the growth needs of the airlines, especially the regional service, as in the whole world, in order to meet current and future passenger demand. On the other hand, the increase in global and regional passenger traffic reveals the fact that airlines serving all over the world have to revise their fleet in order to serve more passengers. This can be seen as a great opportunity for the Qatar Airways to become a global airline from regional airline in these days.

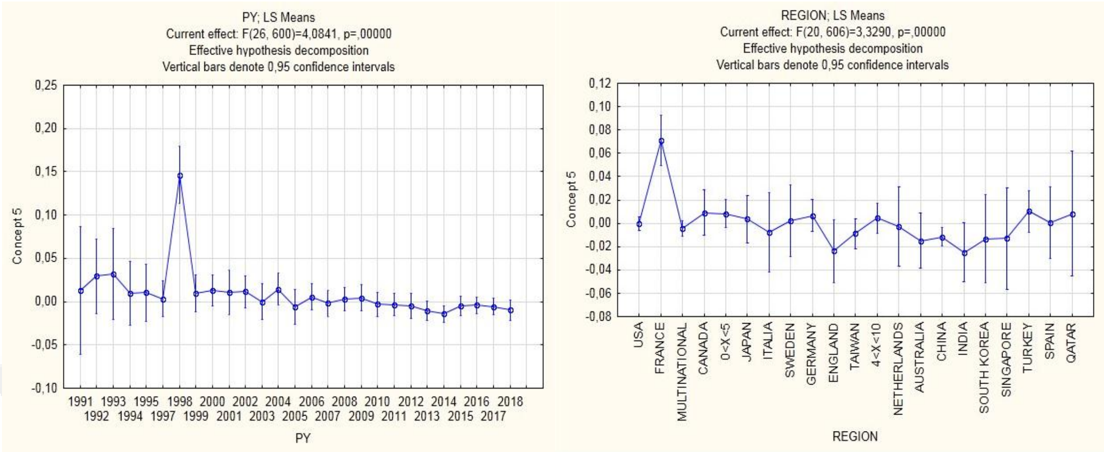


Figure 2.8 Anova for concept 5 vs. publication year/region

Considering Figure 2.8, it can be said that Concept 5 has a stable trend over the years. However, in 1998, concept 5 showed a dramatic increase and accelerated the work done in this area. When the causes of this rise are investigated, the obvious reasons for France's interest in this area can be elucidated that can be made concrete.

In the early 90s, in Europe and Asia, Taiwan's status was controversial. Therefore, Air France was unable to fly to the island under its own name. In 1993, the other subsidiary Air Charter started to fly between Hong Kong and Paris.

However, after Air Charter stopped operations in 1998, a subsidiary called Air France Asie was established[20]. With the establishment of this new airline company, the increase in the number of destinations in France brought an increase in aircraft. At the same time, the increase in the number of airline passengers in Europe and in the intercontinental transportation area required more cabin personnel and pilots. Since this requirement exposes huge costs, many airline companies, particularly France, have experienced effort on crew pairing problems. This is why france has clearly addressed this problem.

In addition to all the findings, the Air Transport Agreement, signed on June 18, 1998 between the USA and France, can be seen as one of the main reasons for the increase in the number of potential passengers in France. Through this agreement, France had many privileges and characteristics in the transport of passengers and cargo to the United States. Also in Germany, Turkey and Canada, can also be seen in the graph that efforts in this regard.

All the reasons explained are sufficient and consistent to explain this relationship. Although the Concept 5 does not have high priority in the analyzes, studies on this concept are still being studied and new methods are developed and brought into literature.

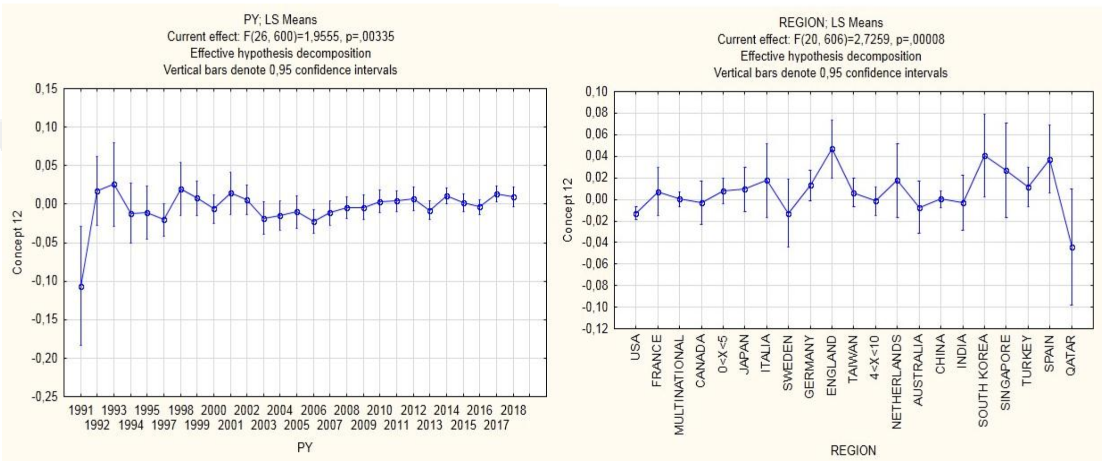


Figure 2.9 Anova for concept 12 vs. publication year/region

Concept 12, which is considered as a significant concept according to 95% confidence interval, has a significant and stable trend in recent years. The Green Fleet Design concept, which has grown from day to day, has remained stable in the literature with the emergence of the first in 1991, which is stable and suitable for development. Figure 2.9 shows clearly that the most prominent among the countries that have worked in this field; England, South Korea and Spain.

The most important reason for the dramatic increase in the green fleet design study area in 1992 is the Kyoto Protocol. The Kyoto Protocol is an agreement of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, pledging to reduce greenhouse gas emissions, based on scientific consensus, in which the states are subject to global warming. Man-made CO2 emissions are highly likely to cause greenhouse gas emissions. The Kyoto Protocol was adopted on 11 December 1997 in Kyoto, Japan, and was put into effect on 16 February 2005, but its effects began to be seen in 1992. Aviation accounts for approximately 2.1 % of globally CO2 emissions

– roughly equivalent to Germany's total emissions. International flights account for around 1.3 % of emissions [21].

In those years, the airline companies, which knew that the increasing number of passengers required more flights, were looking for ways to carry passengers at a lower cost. They knew that lowering the cost of transporting cheap passengers came from lowering the cost per passenger. In addition, the increase in the occupancy rate will take over the costs of the airline and will help to increase the rate of profitability. In those years, British Airways, one of the biggest airline operations in Britain, was one of the participants of this trend. British Airlines' fleet has not changed completely, but by incorporating some of the regional airlines, it accelerated its fleet route and carbon dioxide emission-based optimization studies.

During the 1990s, British Airways became the world's most profitable airline under the slogan "The World's Favorite Airline" [22]. In 1992, British Airways bought the regional German domestic airline Delta Air Transport. At the same time, South Korean researchers were conducting research to prevent carbon dioxide emissions and discussed the effects of aviation on global warming. Also it is known that fuel burn from commercial aircraft increased by 71% between 1992 and 2006[23]. Overall, between 1990 and 2004 CO2 emissions from the EU aviation sector have risen by 73% (Table 7). Six countries (UK, Germany, France, Spain, Italy and the Netherlands) are responsible for 82% of the total emissions. The old 15 Member States are responsible for over 95% of the sector's fuel consumption [24]. All these data explain why these countries care about green fleet management in those years which shown in Table 2.8.

The fact that all of these studies, all of the articles written, shed light on the present and provided us with the opportunity to acquire new information, in fact, give us great ideas and create an environment for us to expand our focus. The fact that the existing concepts are still being studied also explains that these works are ideas that do not lose their value and create new values every day. In the future of aviation studies, it can be said that these studies will be found partially if not completely and will help shape the future.

Table 2.8 CO_2 emissions from aviation in EU member states 1990-2004 [50]

	Emissions [kt CO_2]			
	1990	1995	2000	2004
Austria	918	1 385	1 757	1 724
Belgium	3 108	2 895	4 665	3 825
Cyprus[a]	745	820	898	1 017
Czech Republic	766	499	447	889
Denmark	1 979	2 066	2 504	2 575
Estonia	103	52	65	89
Finland	1 369	1 130	1 408	1 584
France	13 158	15 818	20 534	20 715
Germany	14 487	17 359	21 861	22 040
Greece	3 902	3 819	4 062	4 333
Hungary	475	524	641	609
Ireland	1 118	1 148	1 662	2 223
Italy	5 713	7 304	10 551	10 736
Latvia	221	78	83	149
Lithuania	418	128	81	120
Luxembourg	399	574	972	1 290
Malta	207	333	335	343
Netherlands	4 582	7 625	9 790	10 544
Poland[b]	317	308	358	854
Portugal	1 555	1 764	2 495	2 775
Slovakia	51	65	69	103
Slovenia	82	60	74	62
Spain	7 567	9 519	13 811	15 421
Sweden	2 009	2 060	2 570	2 439
United Kingdom	16 946	21 459	32 212	35 426
EU 10	3 386	2 867	3 051	4 235
EU 15	78 811	95 925	130 856	137 653
EU 25	82 196	98 792	133 907	141 888
Notes:	NE: not estimated			
	[a] Incomplete dataset. 2003 emissions instead of 2004 emissions used.			
	[b] Incomplete dataset. 1991 emissions instead of 1990 emissions used.			

Furthermore, after examining the relationships of the concepts considered as meaningful, some words and the relations of the countries matching the confidence interval were examined. The words studied are frequently used words that are closely related to aviation studies and are still being studied. The scope of these words is evolving day by day.

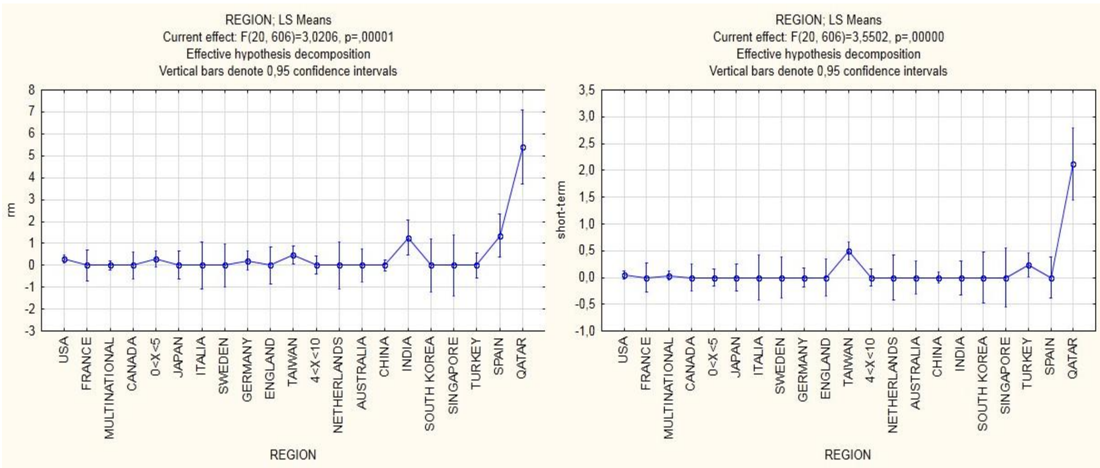


Figure 2.10 Anova for region vs. rm and short-term words

In Figure 2.10 Qatar, which is the prominent country in the analysis of both revenue management and short-term words, worked in this field with a noticeable difference compared to other countries. One of the reasons why revenue management has been given a lot of weight in these studies is that Qatar is a small but high income country. For insance, Louisiana has a GDP of around $207 billion while tiny Qatar has a GDP of around $175 billion and even though its capital city, Doha, has a population just shy of 800,000, according to United Nations data, Doha International Airport's passenger traffic is around half that of JFK International, a city of 8.3 million[25]. The need to manage large amounts of income is not a matter of concern in this sense. What should be surprised is that one of the most of this revenue was created by the aviation sector, which has achieved great success in a short time in Qatar.

In total, Qatar Airlines reported $538 million in profits on $10.6 billion in revenue for the fiscal year that ended in March of 2017[18]. According to OPEC data, Qatar produces 1,552,902 bbl / day oil and meets a total of 592,799 bbl / day / million people oil production in the world. In addition, Qatar is one of the major oil producers in the world, and has been ranked first in 2016 and 2017 in the world's best airline rankings according to Skytrax data. In 2017, it has a second degree. One reason behind this success is the fact that Qatar is producing its own oil and spending the reduced costs on other lines of business and this adds meaning to its work on revenue management. As of 2018, Qatar Airlines ranked second in the Skytrax World's Best Airline rankings behind Singapore Airlines.

The fact that Qatar cares so much for its short-term works is due to the irregular and unsafe airspace in the Middle East. An example of a more deliberate airspace dispute lies in Qatar, where an airspace blockade of the country by its Persian Gulf neighbors continues since June-2017, collectively implemented by Bahrain, Egypt, Saudi Arabia and the UAE, Qatar Airways had its network and financial stoutness directly confronted overnight[26]. The insecure airspace idea brought about by the continuous economic and political uncertainty in the Middle East led to the short-term arrangement of the plans of not only Qatar, but also all of the Gulf Airlines companies, and arranged their flights accordingly. Although there are other countries with large airline companies along with Qatar in the gulf, it is seen that Qatar is the country that has directed the most studies related to short term planning in this region.

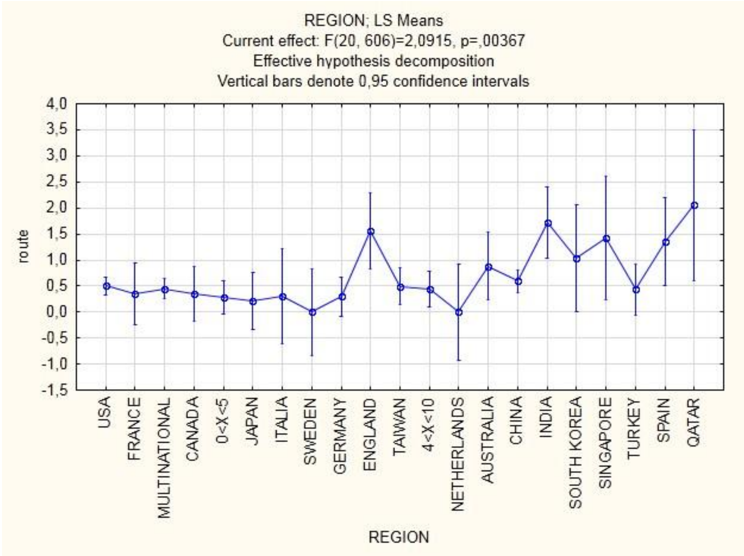


Figure 2.11 Anova for region vs. route word

As a result of this unstable airspace condition, Qatar Airways has launched a new road and network restructuring operation that could be vital for the involuntary carrier. To overcome these constraints, Qatar Airways organized its routes in the blocky countries with 16 new destinations in 2018/19, including plans to become the first Gulf airline to start serving directly to Luxembourg, and took its place at the airports. These initiatives explain why Qatar Airlines came into prominence in routing studies as shown in Figure 2.11.

On the other hand, one of the reasons why the UK attaches great importance to routing is the presence of one of the main hubs of Ryanair. Ryanair is an Irish low-cost airline founded in 1984 that one of the world's top passenger carrier main hub is located in London, at Stansted Airport. In 2016, Ryanair was the largest European airline by scheduled passengers flown, and carried more international passengers than any other airline [27].

Besides, in the British regional airline Flybe, the route network in the region is one of the developed airlines. Headquarter of Flybe Airlines is located in Exeter, England. When calender hits on 3 November 2006, Flybe was announced that would buy BA Connect. Except of the services of airlines which is out of London City Airport and takeover was complete in March 2007. The takeover increased the route network of Flybe in both the UK and the European continent. Thus, Flybe became Europe's largest regional airline.

In addition, India is known to have the 3rd largest civil aviation market in the world [28]. Airline operating in India connects more than 80 cities across India. The liberalized Indian aviation industry also operates overseas routes. Along with Indian airlines, many foreign airlines combine Indian cities with other major cities in the world. However, although the Mumbai-Delhi air corridor ranks third among the busiest routes in the world, a large part of the country's air transport potential continues to be used [29]. Many low cost airlines that entered the Indian aviation market between 2004 and 2005 also contributed to this impact.

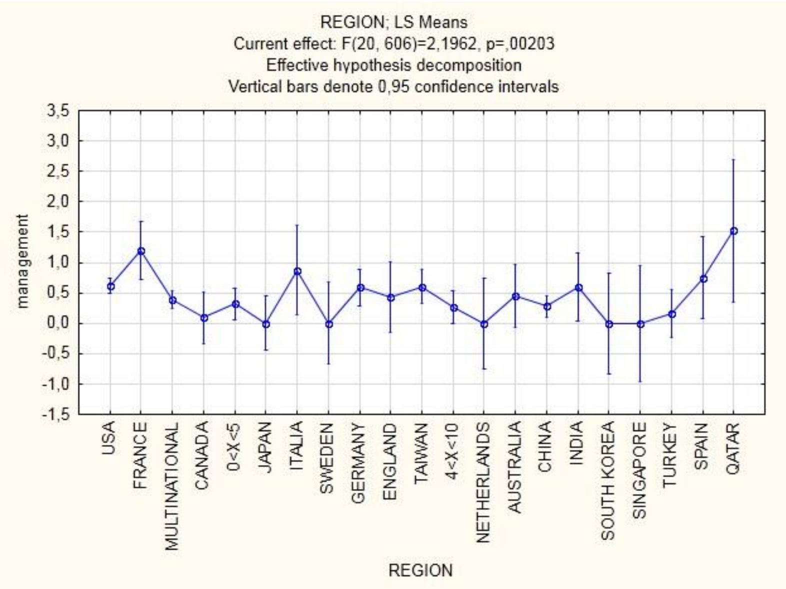


Figure 2.12 Anova for region vs. management word

Qatar's short term planning and revenue management efforts have led to the need to develop a good management style. In order to overcome this situation, it has made efforts to manage the aviation sector, which is one of the most important income sources in the country. This is clearly shown in Figure 2.12. This clearly illustrates the Short-term revenue management concept when 3 words are combined. The fact that it is at the top of the list of the best airlines in the world can also be seen as another proof of management success.

In 2014, Qatar Airways Management began to develop an all-encompassing tool for fleet management and adapted themselves to the need to use evolving technology to scale growth capabilities, management and operations control. In 2015, Qatar Airways eased its policy of restricting the marriages and getting pregnant of the women's cabin crew following the charges of discrimination by the International

Labor Organization (ILO) [30]. This arrangement can be seen as the convenience provided by its employees in order to further improve the success of Qatar and Qatar Airways in management.

Aéroports de Paris is one of the governance authority that operates the 14 busiest airports in Paris, including Charles de Gaulle Airport and Orly Airport. For instance, Charles de Gaulle Airport, located in near Paris, is the forth busiest airport in the world with 60,4 million passenger movements in 2015, and France's primary international airport, serving over 100 airlines. The national carrier of France is Air France, a full service global airline which flies to 20 domestic destinations and 150 international destinations in 83 countries (including Overseas departments and territories of France) across all 6 major continents[31]. Charles de Gaulle Airport is one of France's busiest airports and centers of many European airlines. This has led France to accelerate its work on aviation management in order to manage the growing demand and expanding demand base.

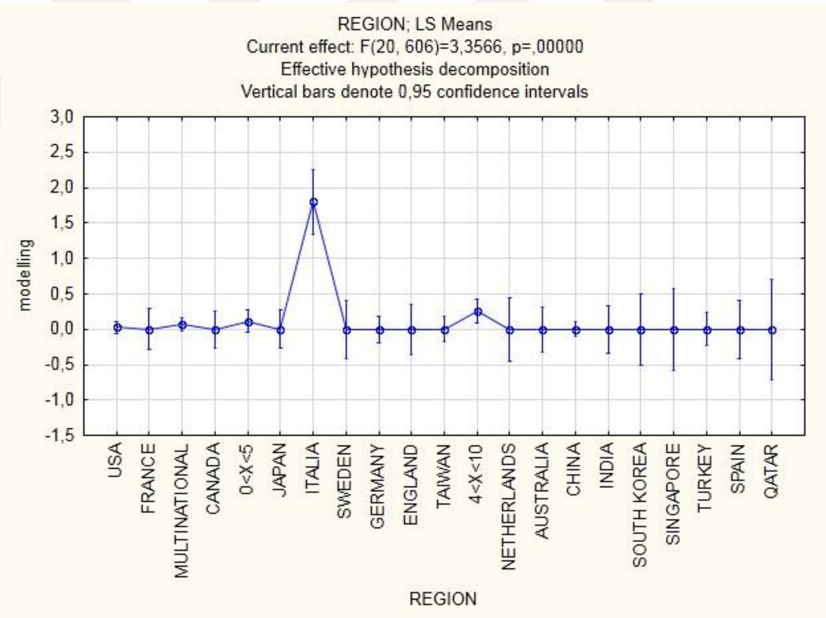


Figure 2.13 Anova for region vs. modelling word

As it can be understood from the Figure 2.13, Italy gives importance to modeling studies in comparison to other countries. It is known that modeling studies are usually performed under major constraints and are made to achieve the initial optimal solution. Alitalia - Linee Aeree Italiane is the national airline of Italy, based in Rome. The company has not made a profit since 2002. Giancarlo Cimoli, the director of the company in 2004, is trying to cut back costs by reorganization. In a statement made in October 2006, he announced that they had cash for 1 year to survive. The fact that Italy is in the bottleneck of the national airline and is in search of a new way to survive gives an idea about speeding up the modeling studies in the country. large-scale cash shortages have the potential to create problems in flight operations and labor-related operations. It is normal for modeling studies to make the money to be spent wisely.

After Alitalia's bankruptcy in August 2008, Compagnia Aerea Italiana (CAI) acquired the Alitalia brand and some of its assets. The new Alitalia does not have most of its working planes currently. Almost every aircraft from CAI's former Alitalia has been sold or decommissioned. This decision, which changed the future of the Alitalia fleet, allowed the creation of a new fleet. Alitalia-CAI airplanes are leased mostly from Aircraft Purchase Fleet according to company's need. During this new formation process, the efforts to determine the priorities of the company, to accelerate the modeling studies during the decision-making process of the new fleet and the renewed face of Alitalia which is the flag carrier airline of Italy, reflects the positive results of these modelling studies.

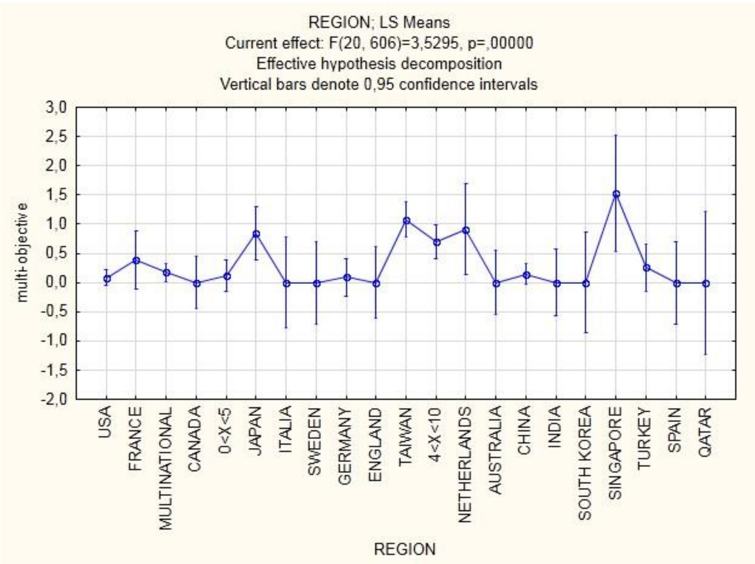


Figure 2.14 Anova for region vs. multi-objective word

In Figure 2.14 aviation in Singapore is a key component of the Singaporean economy in its quest to be a transport hub of the Asian region. Besides currently the sixth busiest airport and the fourth busiest air cargo hub in Asia, the Singaporean aviation industry is also a significant aerospace maintenance, repair and overhaul centre[32]. Furthermore, the aviation sector is one of the parts that make up the large amount of revenue in Singapore. Singapore Airlines is the flag carrier airline of Singapore with its hub at Singapore Changi Airport. It is ranked as the world's best airline, since 2018, while winning the top spot in three other categories in the same year including "Best First Class", "Best First Class Airline Seat", and "Best Airline in Asia[33]. The fact that multi-objective-based studies are mostly conducted in Singapore is likely to result from the location of the Singapore. As mentioned earlier, Singapore is one of the biggest maintanance and repair and overhaul centers in Asia. This is one of the factors that directly affect the income of the aviation industry. In 2009,it is known that aviation industry contributed S$14.2 billion in direct and in-direct value-add to the Singaporean GDP.

Singapore-based airlines have played an important role in logistics operations, both in terms of passenger transportation and a key link in the supply chain, and supported the manufacturing sector in this manner. This is an example of the fact that studies in the name of aviation in singapore are carried out not only in a way that concerns the aviation industry, but also in harmony with other sectors. While the studies on the aviation sector are carried out, the fact that multi-objective subjects are selected corresponds with the mentioned reasons. This situation directly contributed to the national economy and supported the development.

Moreover, Skyteam is the airline alliance of 20 countries and center is located in Netherlands. In March 2014, SkyTeam flies to more than 1000 destinations in 178 countries and can host up to 15,700 flights per day with a combined fleet of over 4,400 aircraft, including the common carriers [34]. The Alliance have a total workforce of 459,781 people. The tremendous fleet, flight network and labor potential of the Alliance have helped accelerate the multi-objective based studies in aviation sector of the Netherlands.

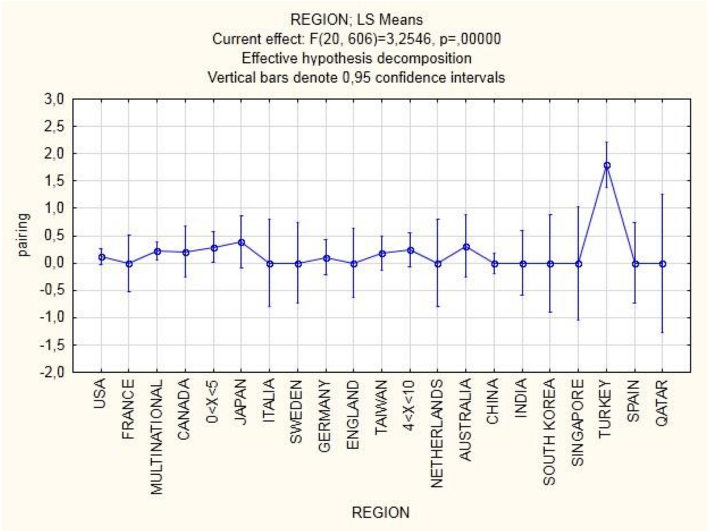


Figure 2.15 Anova for region vs. pairing word

As a result of the analyzes conducted and presented in Figure 2.15, Turkey is the country has done a lot of work in the field of pairing (Crew Pairing, etc.). When the causes of this condition are investigated, there are a few main reasons. One of the reasons is the rapidly developing population, increasing the number of passengers carried by the airline and increasing the need for cabin crew every day. In parallel with this, Turkish Airlines has increased its capacity with its growing fleet every day and has created areas that can be worked in this field. In addition tihs, Pegasus Airlines is the low cost airline which is another important airline in the country, also meets the airline's needs with Turkish Airlines. In 2018, Turkish Airlines received the title of Europe's best airline company at the Business Traveler Russia and CIS Awards award ceremony. With the acquisition of this title, efforts were made to improve service systems and increase operational capability in order to protect them.

Furthermore, due to its geopolitical position in which Turkey is located between Europe and Asia is assuming the role of a bridge that both these airlines have flight network to provide privileges in terms of both the number of destinations. Turkish Airlines flies to 47 domestic and 230 international destinations in 119 countries currently. Turkish Airlines still holds the title of the airline with the most flight destinations. Turkish Airlines need labor force day by day because of its location and the missions it undertakes and has set an example for the works in this field. Also Pegasus Airlines is one of the companies that has created source for studies that deals with many of the daily domestic operations.

With all these efforts and professional feedback, Turkish Airlines is able to optimize the management of its crew of approximately 8,000 to improve operational efficiency. Turkish Airlines, which is the flag carrier of the country for all these reasons, provided resources to researchers in order to perform their operations in a healthy way and to provide the best service. As a result of these efforts, Turkey has the leading position in studies conducted in this area.

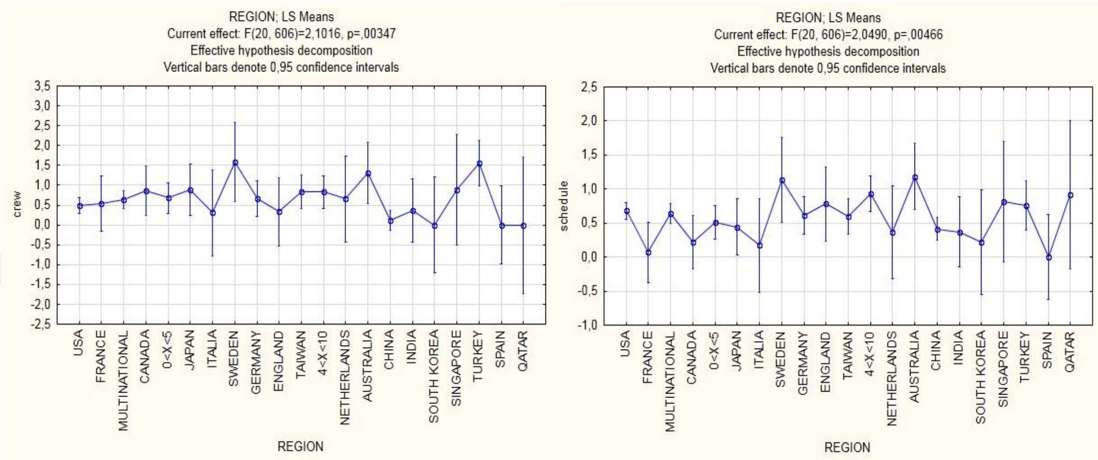


Figure 2.16 Anova for region vs. crew and schedule word

The last one of the analyzes given in Figure 2.16, crew and scheduling words are examined in the anova Table. The work carried out in this area is the most widely carried out by Sweden and Australia. It is known that aviation is of great importance to Sweden's economy and competitiveness. The basis of Sweden's intensification of its studies on crew scheduling can be predicted as the state-set strategies. The transport policy objectives and the Swiss Government's objective to achieve the lowest unemployment rate in the EU by 2020 serve as the starting points [35]. Swiss Government states that the export strategy and the aviation strategy will provide the conditions to jointly strengthen trade promotion in the Swedish aviation sector. It is reported that Scandavian Airlines SAS had a market share of approximately 70% in the Swedish market for scheduled domestic passenger flights in OECD documents. In addition, increasing the number of passengers with bonus applications in the region increased the number of passengers in this area will increase the amount of flight triggered work related to crew scheduling. The development of the Swedish aviation sector brings with it the necessity of regular scheduling and control of both labor and aircraft.

On the other hand, The aviation sector is a significant contributor to the Australian economy contributing in excess of $30 billion per annum and employing in excess of 250,000 people[36]. In a meeting which is done in 2016 named as *The Australian Aviation Associations Forum - Aviation Policy*, states that the industry will not only require large numbers of additional pilots and new maintenance staff, but also additional air traffic controllers, operations managers, ground handling staff, airport staffs. Again, one of the most popular strategy called "à la carte" pricing strategy, which has been followed by most Full Service Carriers, has increased customers' choice and reduced prices for basic services in UK and Australia widely[37]. This situation, which increases customer demand, has increased the amount of flight and triggered more effort in flight planning and crew scheduling.

While Australia has a good position to offer full aviation education opportunities to both domestic and international students, the efforts to increase the workforce in the aviation sector that will be directed in the future are blocked by Australian regulatory and licencing regime[36]. In order to overcome all these situations, it can be said that Australia accelerated these studies.

2.4 Conclusion

The aviation dream, which started with the wright brothers, faced many difficulties in many types, but it managed to maintain its place. This study analyzes recent research and developments of airline optimization applications in aviation sector. It also examines trends and makes inferences. From 1991 to the end of 2018, more than 700 publications were published from Thomson Reuter - ISI Web of Knowledge, one of the most widely used web databases. With this study, an idea about the tendencies that hold a big place in the world and which shed light on the future of the aviation sector, which has a big impact on the economy of many countries. The International Air Transport Association (IATA) predicts that in 2035, there will nearly 7,2 billion airline passengers. This means that a flight will take place for almost every person in the world. To compare, there were 3.8 billion air passengers carried in 2016 and total revenue was 709 billion $.

The aviation sector, which plays an important role not only in its economy but also in the technological development of the country, is such a sector that needs to be scrutinized in order to be better positioned in the world according to become more powerful. In this sense, knowing the trends in aviation and the optimization studies in the aviation sector is vital for the countries in the world to shape their future aviation policies. Extensive analysis of the study revealed some trends and clusters. These tendencies and clusters are actually small signals of key points that can create bottlenecks in the sector. In line with these signals, taking early preventions can provide great advantages to the aviation industry, which has a higher cost compared to other sectors, can save the future in a sense. Thus, it is important to remember that every activity to be made today will leave a mark on the future. The trace left to the future is only possible with change. The primary drivers of change are society, technology, environment, economy and politics. Nowadays, these 5 cases, which are seen as the pioneers of change, enrich and expand their scope very quickly from day to day. Some of the effects of these changes are seen in our concepts in our study. For example, Concept 1 is called Aircraft Operation Network Scheduling and can be considered as the result of reaching every point in the world and as an impact of the world's consumption needs.

This is described in the IATA's " *Future of Airline Industry 2035* " report; The importance of emerging markets, economic growth and the appetite of developing countries on natural resources can increase global prices and make it more difficult to structure supply chain assets[38]. Therefore, it is possible to overcome this difficulty by restructuring and scheduling of airline operations networks as a primary transportation tool in supply chain. The discovery and scheduling of new operation networks triggers crew scheduling and pairing problems. Because the new flight networks, which are caused by increasing demand, have triggered the need for cabin crew with many different reasons as mentioned in Concept 5 content. International political uncertainty and terrorism also play an important role in the selection, scheduling and discovery of operations networks and it was also referred to as geopolitical instability in the report by IATA. They says that the next 20 years, state fragility, religious and ethnic problems, and pressure on Global resources may trigger conflict [36]. Even if the problem of supply chain pressure and geopolitical turmoil of changing world structure is assumed to be solved, the shortage of oil in the future world reveals a new problem. It is known that fossil fuels cause climatic and geopolitical problems due to conflicts of interest in the world mainly.

The aviation industry is one of the flag bearers when it comes to monitoring carbon footprints. In order to overcome this issue, many alternative fuel studies have been carried out recently by many researchers. The search for alternative fuels to replace fossil fuels has brought another perspective to the aviation industry. One of these perspectives was to investigate whether a green airline fleet was possible or not. Tupolev Tu-155 can be given as an example for green passenger carrier in this circumstance. Tupolev 155, which emerged as an experimental plane, met with the sky on 15 April 1988. A normal passenger jet with a Kuznetsov NK-88 engine consuming liquid hydrogen was produced, and was running on alternative fuel.

In this context, this study revealed Concept 12 called as Green Fleet Management. For this concept, IATA seeks the answer to this question; Can air travel stand out in a more sustainable world? Along with these studies, it is aimed to reduce the amount of carbon dioxide released by fossil fuels into the environment and to prepare the base for a more stable climate. Recently, some airlines have announced that they will support the “*Carbon Offset and Reduction Scheme for International Aviation*“ (CORSIA) since 2020. This statement is one of the steps taken for environmentally friendly aviation with a more stable climate and less carbon dioxide emissions.

IATA, which is one of the oldest international organizations of the airline sector, aims to utilize some of the initiatives that it is currently conducting and utilizes it for the purpose of predicting the future. Among the aims of this study is being a light for the future of aviation sector and studies, contributes to this mission existing. Identifying the types of this mission in the future can be seen as important as contributing to the mission. Some concepts were determined as future effort areas of aviation. Determined concepts are examined and justified in the framework of logic.

As a result, for more robust and consistent aviation in the future, importance should be given to airline optimization studies and examined carefully. While carrying out all airline operations around the world, environmental factors should be considered and new methods and inventions should be sought in order to minimize environmental damage. In order for the world we live in to be a better place in the future, great attention should be paid to every optimization study that avoids wastage, not only in airline optimization studies. Thus, it is possible to summarize the results as follows.

- The most popular airline optimization efforts are airline flight network design, variable flight crew pairing and green fleet design nowadays.
- If there are geopolitical dangers or uncertainties in or around the country of destination, route planning and fleet selection are crucial.
- In relatively developing countries, airline optimization studies tend to focus on use of human-oriented variations of existing technology and optimization more than technology development.
- If the location of a region is suitable and can be used in several logistic modes, airline optimization studies become multi-objective with integrated approaches.

One of the most important conclusions were reached about the Turkey. Due to the geographical location of Turkey, is in Europe and Asia's hub for transit and transshipment point. Airline traffic is crowded and becomes more complex to manage every day. In the airline industry in Turkey this complexity creates a preoccupation on the available capacity because there no airline which is serving just for domestic voyages in Turkey and most of the flights are necessarily associated with international flights. In these circumstances, this problem causes delays in airports, reduced passenger satisfaction and blockage of decrease in ticket prices. Therefore, this study will be held in subject of aircraft selection to create a new fleet to serve only in domestic routes and flight network design for Turkey. Future in the skies!

CHAPTER 3

PROBLEM DEFINITION AND LITERATURE REVIEW

In this thesis, text mining method is used to reach comprehensive definition of the problem. As a result of the usage of this tool, the existing problems in the field of airline optimization were taken into consideration and the subject of thesis was determined. This chapter expresses main problem of thesis and definition of it also literature search in the light of the results obtained.

3.1 Problem Definition

Topograpgy of Turkey has a specific characteristic in road transportation is common in this state because of many provinces close to each other. Because of this adjacency, many citizens carry out their transportation activities by road. However, with the changing world order and resource utilization, road transport is becoming less popular, because the rise in gasoline and diesel prices triggers this situation. In addition, the speed limits and judicial fines imposed on highways lead to the loss of time and money of passengers in the road. In this area, it is difficult to reach exact statistical data but total passenger transportation and number of buses are shown in Figure 3.1

Although the number of passengers and buses fluctuated over the years, an upward trend is known. It is expected to continue its upward of this motorway transportation trend because of economic status of Turkey. Just because it is known that the most common mode of transportation in low-income and middle-income countries is road transportation [39].

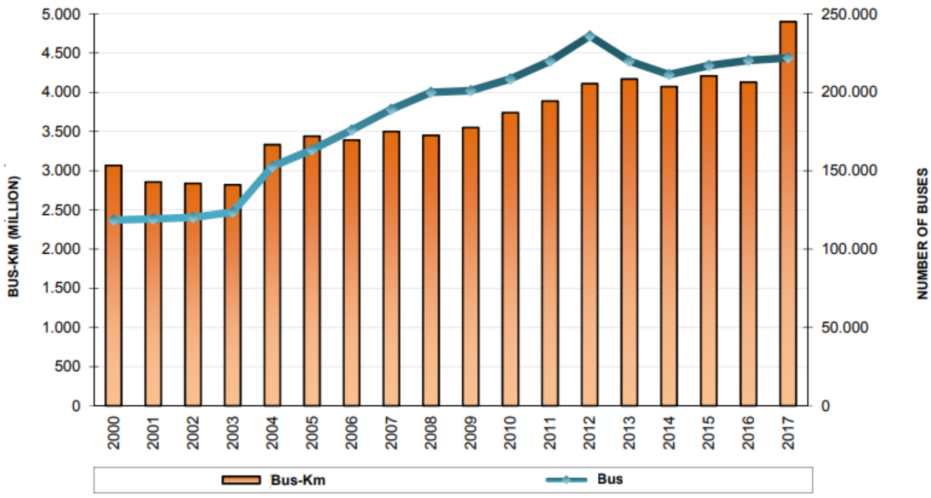


Figure 3.1 Comparison of bus-km and number of buses

However, as in Turkey lose of time semantically occurs equivalent to losing money when the roadway used. This circumstance pushes people to use airline transportation, which is a faster and more comforTable means of transportation. However, the fluctuations in income level and the cost of economic inputs prevent this situation shown in Figure 3.2.

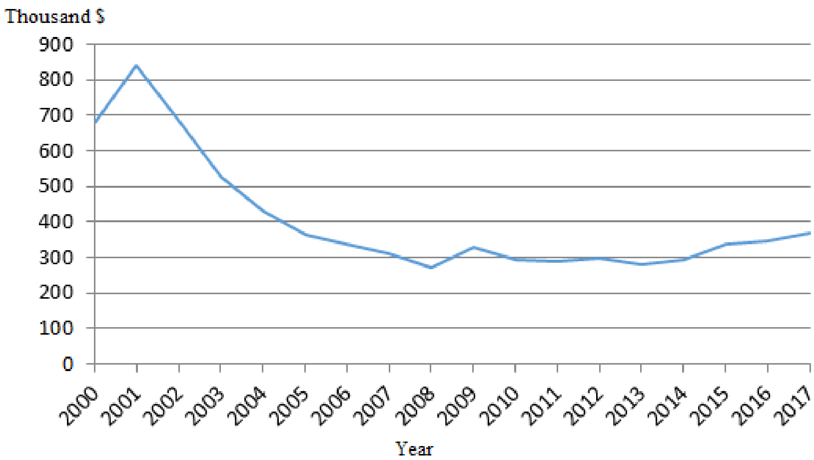


Figure 3.2 Road passenger transport in passenger-km per one thousand units of current USD GDP of Turkey by OECD [40]

Road passenger kilometer graph, which is equivalent to USD thousand units in given year period is given above for Turkey. As can be seen, there is a significant downward trend in the chart. This situation reflects the depreciation of the Turkish Lira against the US dollar. This loss increases costs and reduces total available passenger mileage.

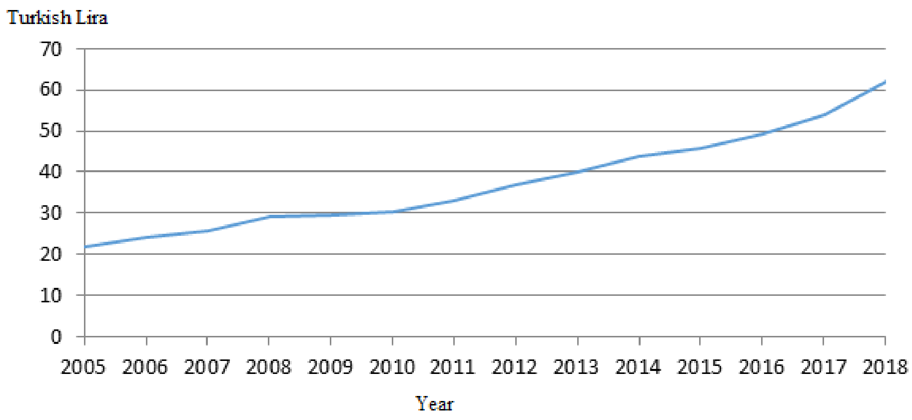


Figure 3.3 Average bus ticket price change in Turkey

Road transport, which is already exhausting and relatively costly, becomes even more unbearable. However, the cheap and accessible bus tickets keep the demand for this type of transportation active at all times. In addition, purchase of bus tickets without reservation, flexible departure times and accessibility make people prefer this mode. Moreover, the relatively expensive cost of non-competing air transport makes this mode of transport unattainable also shown in Figure3.3. Because, fleet of existing airline companies in Turkey is not fit to perform just for domestic or charter flights.

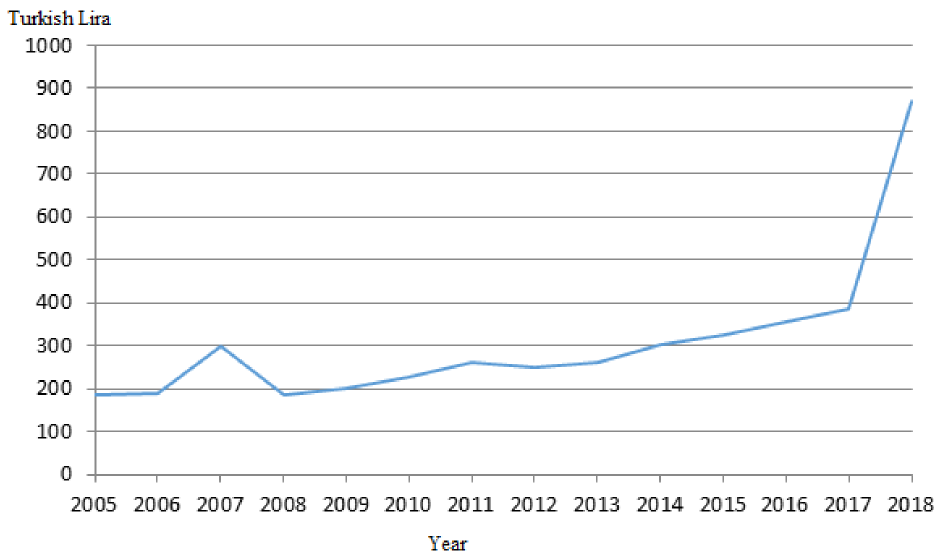


Figure 3.4 Average airline fare change in Turkey

As can be seen in Figure 3.4, graph of average airline ticket fare change in airline traffic, the majority of which is composed of domestic passengers in Turkey, is analyzed . The stability in price increases causes airline transportation to lose its competitive advantage over road transportation.

Therefore, according to Porter, powerful customers can catch more value by lowering prices, demanding better quality or more services (thereby increasing costs) and playing against industry participants, often at the expense of industry profitability [41]. In Turkey, the air transport market in the private sector, competition among companies in the sector began to take a more active role which observed in the number of passengers using low prices and ultimately the airline industry competitiveness is seen brought serious increase occurs. The fact that airline companies can also offer cheaper transportation and transportation services increases the number of initiatives in this field and has increased the popularity of this mode of transportation. Air transportation, which has significant advantages over other types of transportation, is also becoming a sensitive transportation type in terms of economic, political and environmental factors.

In this regard; the necessary investment costs for the establishment of transport networks and fleets, the subsequent costs associated with the movement of vehicles on transport networks, ensuring safety and control, and the necessity of modern noise reduction systems play an important role[42].

3.1.1 Environmental Impact

However, it is also necessary to consider the environmental impact of all these transport activities. Regardless of which mode of transport, all types of transport are known to contribute significantly to carbon dioxide emissions in world.

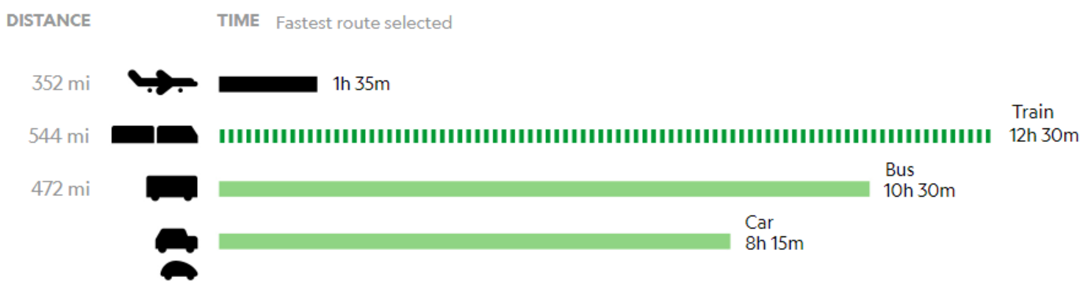


Figure 3.5 Travel time between New York and Toronto

As seen in Figyre 3.5 the shortest time to reach the vehicle is the airline vehicles. However, this does not give us an advantage in energy efficiency and in reducing the carbon footprint. Although it is efficient in terms of fuel consumption, it is very inefficient in terms of carbon footprint presented in Figure 3.6.

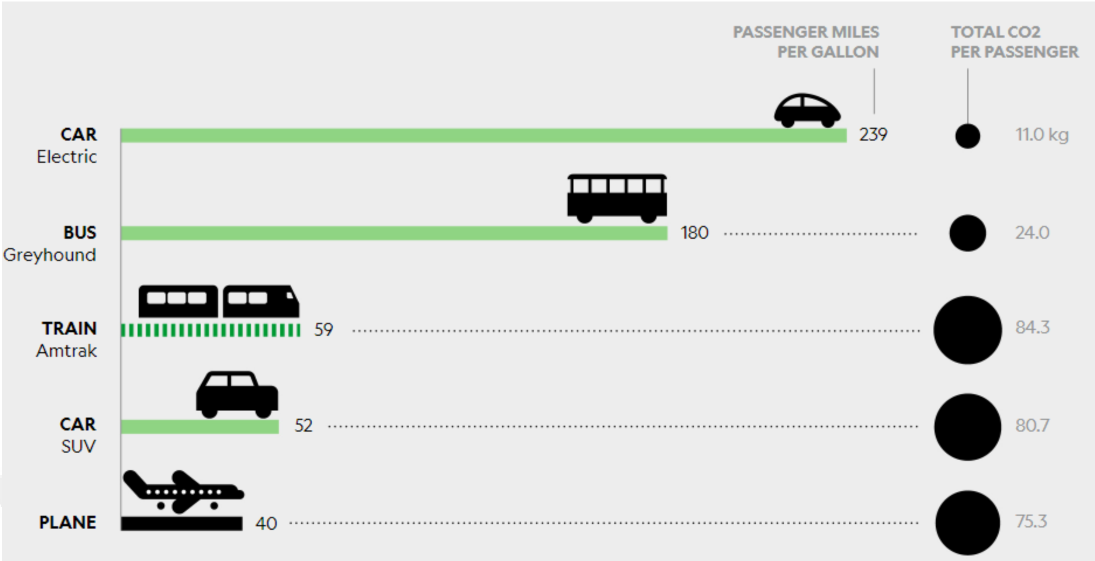


Figure 3.6 Carbon footprints and fuel consumption of transportation modes

Lighter materials, improved aerodynamic designs and more efficient engines have increased the distance each mode can travel with one gallon and these improvements are taking place much faster as they continue from the past to the present. Following formula may be sufficient to recognize the carbon footprint and carbon dioxide emissions per flight.

$$TCDE = FC \times COE \times DF \times Cst \qquad (3.1)$$

where;

CDE = Total Carbon Dioxide Emission

FC = Fuel Consumption of Aircraft

COE = CO2 emission of Aircraft

DF = the distance flown, in kilometers

Cst = Radiative forcing constant that is 1,9

As an example of calculation to show carbon dioxide emission per flight, As an example of calculation to show carbon dioxide emission per flight, An Airbus A320 consumes 2,43 L/100 km kerosene approximately [43]. 3.2kg CO2 is emitted per liter of aviation kerosene [44]. Overall, it produces 0,148 kg CO_2 per passenger kilometers.

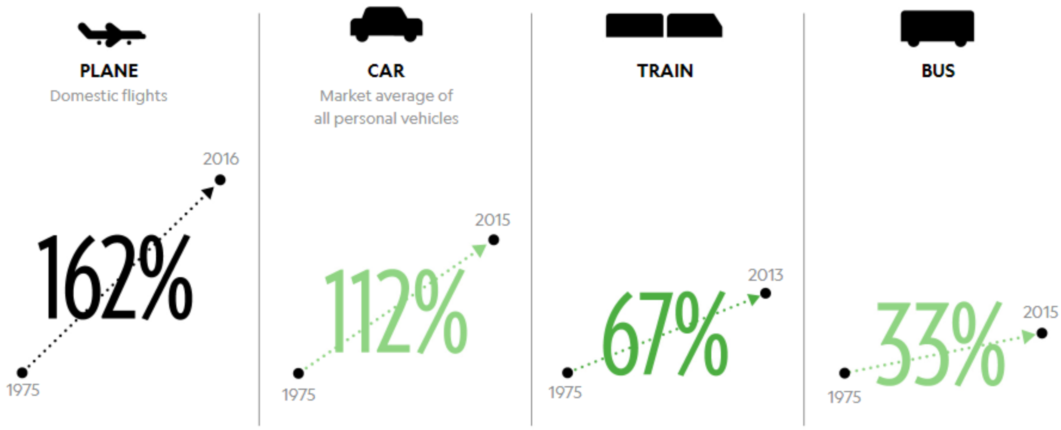


Figure 3.7 Improvement on prevention of CO_2 emissions from 1975 to 2016

R&D studies and innovation-centered researches have been found as a new field since 1975, making it the area where the most improvements are made in the airline sector. Thus, it can be said that the aircraft serving the airline sector will become much safer and healthier in the future shown in Figure 3.7.

Necessity of a new domestic airline for Turkey which is explained in detail in section 3 is supported by the data. On the other hand, there are existing questions and comparisons existing which is required to reach answers. These questions are as follows;

- Which type of decision making tool is used to determine the type of aircraft which will use to construct fleet in literature ?
- How will design for flight network and these fleet assigned to routes
- How will the demand of possible passengers be anticipated and evaluated when designing?

Thus, the outline of the planned studies in Turkey is created and has been formed for the purpose of moving the necessary questions. In the present literature, it is clear that the problem of fleet selection has been studied and is one of the famous problems. However, the selections are economically oriented and the potential benefit is overshadowed. Decision-making problems are realized by considering the reasons such as increasing profitability and lowering costs. However, many time occupancy rates are not considered.

Therefore, many problems studied deviate from the purp se. Because the plane you have not filled is theoretically efficient, but it is not efficient and valid in practice. The mathematical models studied do not take into account the intentions while leading to the optimal result considering the constraints. Whence, there is a large gap between in determining the intentions and priorities of decision makers in fleet selection problems.

In addition, many conclusions are reached in network design problems without comparing the Hub and Spoke and Direct Link approaches. Because schedules for direct flights are always profiTable and less risky because you have no dependent variables other than yourself. However, it is never clear how these approaches can yield results for which geography. Therefore, the academic network design mentality as performed previously in Turkey should be compared and the results should be explained clearly.

In the light of this information, as a continuation of this section, the studies on fleet selection problems and flight network design issues are examined in current literature. Approaches, assumptions and tools used in both fleet selection problems and flight network design problems. Integrated approaches are also included in the review.

In Chapter 4, selection of the fleet is explained to be made by the determined methods and models. The data and constraints used for fleet selection are defined. Extracted results are shown and discussed. At the end of the fleet selection , flight network design was made by using the data obtained in Chapter 5.

3.2 Literature Review

With the advancement of technology, aviation and aircraft have always been the center of attraction. This fascination has attracted the attention of researchers and engineers and they have accelerated their studies in this field. Somehow, improvements on data creation rises day-to-day data analysis has become impossible, and studies now reveal large data. Information generated by the analysis of these data needs to be managed.

At this point, the condensed opportunities created by the developments made in the name of aviation brought many problems and problem diagnosis methods together. These problems and methods of diagnosis are mentioned in Chapter 2 and Chapter 3 in detail. Fleet selection problem, which is one of the main problems, is a common problem and field of study. Because the selection of fleets, the primary driving force of aviation operations, is a laborious, exhausting and costly task. Likewise, the process of managing fleets is as complicated and laborious. However, the establishment of a fleet in line with its purpose and capabilities is both a great opportunity to meet the need and a major driving force behind economic development for companies and countries.

3.2.1 Tracing on Current Condition of Aircraft Selection Techniques Methodology

Fleet selection and assignment problems have been studied by using many different methods and models in this field from past to present. Multi criteria decision making tools have attracted intense interest in selection problems rather than assignment problems. There are studies that can be a pioneer in this field. The first of these studies was done by Marsten and Muller [45]. Marsten and Muller dealt the design of the service network and the selection of the cargo aircraft fleet to establish a long range plan. Development of this plan included the selection of the most profitable routes and aircraft types. This approach, which handled selection and design problems together, was realized with a mathematical model. In addition, the constraints of the mathematical model created were due to the potential characteristics of the candidate aircraft. Later, with the development of aircraft and expanding fleets, these problems have been replaced by problems of assignment.

Wang and Chang developed an valuation approach based on the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), to support the Air Force Academy in Taiwan. They tried to determine optimal initial training jet in a fuzzy environment where the ambiguity and subjectivity are handled with linguistic terms parameterized by fuzzy numbers [46].

Today, there are different approaches to fleet selection problems literally. These different approaches emerged with the integration and comparative use of mathematical models and MCDM techniques. One of these studies, and the study conducted by Turcksin et al., includes the definition of the policy that should be followed in order to form a green vehicle fleet by using the Analytic Hierarchical Process (AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) approaches. [47].

Sun et al, was performed a study which reveals the implementation of various MCDM techniques on aircraft selection problems to form a fleet also shows the potential application of MCDM procedures in the appraisal of air transportation systems, considering with balance of economical, ecological, and technical constraints [48]. Özdemir et al. also performed an aircraft selection study with Analytic Network Process (ANP) by using Fleet data of Turkish Airlines which is the biggest company serving in Turkey to revise aircraft fleet of flag carrier company [49] .

Dozic and Kalic investigated an process about aircraft selection with AHP and monitored enabling improvements by considering change on behavior one of element in pairwise comparison matrix while others constant [50]. Again, another study conducted by Dozic and Kalic also compares AHP and Even Swaps Method (ESM), which multi-criteria decision making methods for aircraft selection problems, and include sensitivity analyzes [51].

Bai et al. used a rough set theory to overcome the restrictions of the Vise Kriterijumska Optimizacija IKompromisno Resenje (VIKOR) method to develop a renewed MCDM model considering decision makers' (DM) judgments [52]. Another purpose of this paper was to introduce a new hybrid approach for guarantee sustainable transportation instrument evaluation and selection by integrating a triple parameter grey interval number with a set theory and VIKOR technique.

On the other hand, the study conducted by Sawik et al. compares the ability of MCDM methods used for truck fleets to be established for a food company but not for under different strategy approaches by considering environmental aspects in terms of green fleet design [53].

Lee et al. was proposed a multi-criteria decision making (MCDM) approach which combines the decision-making trial and evaluation laboratory (DEMATEL), analytic network processes (ANP) and zero-one goal programming (ZOGP) to reach optimal green aviation fleet administration strategy decisions [54]. Also they evaluate their methods could be used more extensively to various green airline fleet management occasions.

Dozic et al. was used another aproach called Fuzzy Analytic Hierarchy Process (FAHP) based approach. To derive crisp priorities from matrices, a logarithmic fuzzy preference programming (LFPP) method is utilized, as well as an sophisticated LFPP method [55]. Also they showed the applicability with regional airline case study of methodology proposed.

Finally, Gomes et al. was used MCDM method called as NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) to select a type of aircraft for Brazil which will be used for regional chartering in [56] .

3.2.2 Tracing on Current Condition of Flight Network Design Techniques Methodology

Flight network selection problems have attracted and studied many times. The hub-and-spoke design problem consist of the smallest size of fleet with their routes and or paths to minimize total operating costs. When the literature is examined, Spiller is seen as the person who has studied the basics of this subject in detail [57]. Spiller examined the relationship between hub and spoke approach, which is one of the approaches used in flight network design, to airline pricing policies and investigated its usability. In the same years, O' Kelly and Lao approached the Hub and spoke problem from a different side and proposed a new mathematical model [58]. Proposed model is solved a mathematical model under four different levels of delivery time, and the results show that as the promised delivery schedule is relaxed.

Kuby and Gray also done a research which deals with network design problem for hub and spoke approach by considering stopovers and feeders in Case Study to Federal Express [59]. The main topic investigated was to develop a mixed integer program that can define the spoke points that can be selected when hub location is defined. Dobson and Deberer also revised and presented the mathematical model for route planning and scheduling of airlines to maximize profitability [60]. In addition to mathematical models, the studies carried out include selections made using heuristic methods.

On the other hand, Aykin considered the hub and spoke technique used in airline network design problem as lagrangian relaxation based problem [61]. In this problem, hubs have limited capacity for flows between nodes which served by the system. Also, problem is formulated under a networking policy which empowers both direct and hub connected services between service nodes. Aykin also investigated pricing policies for airline carriers in Hub and Spoke systems which covers different pricing policies [62]. These policies were created not only for passenger transportation but also for cargo transportation.

Bryan and O 'Kelly wrote an analytical review of hub and spoke networks in air transport [63]. This review covers and examines all hub and spoke studies written in the field up to that year. In another study by O 'Kelly and Bryan, it was shown that economic constraints and policies observed when determining hubs and spoke could adversely affect the model and create false economic scales [64]. They also touched on the paths to be followed and the policies to be established in order to achieve proper results.

Sasaki et al. was developed a study which deals selection of hub airports by using p-hub median problem [65]. They proposed a branch and bound algorithm and greedy search algorithm. While they were constructing the problem, considered the 1-stop multiple allocation p-hub median problem. As a different perspective, Nero has developed various analyzes of the comparative advantage of hub and spoke networks [66]. They concluded their study as nonetheless there is a competitive advantage to increasing the size of a network. Hendrick et al. was determined the entry and exit conditions of hub and spoke networks for airline companies [67]. In fact, their study was to investigate the suitability of regional airline carriers for hub and spoke networks. They tried to give possible answer to question of why regional carriers may not survive in hub-spoke networks.

After that, Büdenberder et al. were developed an approach which consist hybrid algorithm by using tabu search and branch-and-bound algorithm for the direct flight network design problem [68]. In the 2000s, the course of the studies changed and development problems came to the fore.With the development methods and approaches come to the fore, the studies in this field have evolved. One of these studies was done by Hsu and Wen [69]. Hsu and Wen, together with two submodels, discussed the problem of flight selection and flight frequency determination. In addition, supply-demand convergency was observed in the realization of these models.

In the study conducted by Eldahli and Hu, the congestion situation in hub and spoke networks was discussed and this problem was given to more realistic perspectives [70]. This inferences are achieved through a non-linear objective function that is linearized in cost term. Lin and Chen have proposed a hub-and-spoke network with constraint of capacity and directed network configuration that combines the operations of common hub-and-spoke networks [71]. These common hub and spoke networks include pure, stopover and center directs. They tested results of study on FedEx AsiaOne air transportation network.

Also Kim and Barnhart dealt with flight schedule design for a charter airline which is one of the focus area of this thesis [72]. They made this study with real data which handled by an airline. They also analyzed the efficiency of the models by using heuristic approaches in addition to mathematical models. Yang worked to determine the hub location by taking into account seasonal fluctuations with a stochastic model [73]. After this model, routes were determined in connection with hub points and the results were discussed. The study was based on taiwan air freight transportation.

De Camargo et al. again worked on the design of hub and spoke network under congestion conditions but worked with multiple hubs [74]. Up to 81 nodes were studied and a model based on mixed integer programming model was solved. On the other hand, the study conducted by Aguirregabiria and Ho investigates the conditions of entry of airline carriers into hub-and-spoke networks and how profit functions are positioned under these conditions [75]. They analyzed competition conditions and deterrence conditions and share the results.

In more recent times, mathematical models can be seen that are tailored to customer demand to keep up with the dynamic nature of the system. One of these studies was carried out by Hsiao and Hansen which includes air passenger based model that deals with demand generation for pair of cities and demand assignment [76]. An et al. were made a study to define a realistic hub and spoke design. This study introduces models and algorithms in detail to ensure the realism of the model [77]. Thus, they propose a set of credible models of hub and spoke network designs , where the pick of backup hubs and distinct routes are taken into consideration to energetically handle hub disintegrations.

Kenan et al. was proposed a model to reach more robust planning stage for fleet assignment and flight scheduling by considering demand and fare change in highly uncertain environment [78]. This model is built with various stages which consist of flight leg determination , fleet assignment of legs based on demand and fare substantiation. At last, Zhao et al. developed a rule-based strategy by using optimal acts to be ensure air traffic flow between airports. Also, possible routes was determined in order to select in emergency circumstance [79]. They handled this problem as allocation problem which mimics the network design conditions.

3.2.3 Conclusions

The use of decision-making tools is much more important in a period where decision-making processes become more difficult every day. Dynamic environment and economic conditions, which change hourly, force decision makers to be adaptive and make the decision-making process faster. These constraints are becoming ever more stringent and the problems that need to be solved become more complex. Therefore, many decision makers endeavor to utilize analytical methods and expert systems to solve the problem they have . These analytical tools are known as multi-criteria decision-making methods. On the other hand, mathematical methods are frequently used to solve these problems.

However, since the complex problems presented by the dynamic environment and economic sanctions cannot be solved by conventional methods, these tools are now hybrid and more intuitive and require and demanded more information from a decision maker. Contexts and objectives of the methods used in this case have also evolved. Aircraft selection problem is a complex and dynamic problem with many constraints and differences between countries and varies according to geography towards construct a regional fleet. As shown in detail in this chapter, the geography where Turkey is located does not have a precedent about the problem. And yet that is seen, there is a large gap in this area of work between the world and Turkey. These reason led to this part of this thesis.

The curiosity that has continued since O' Kelly's first work in this field about location of interaction hub facilities [80] has increased the work in this industry every day. On the other hand, most of the studies carried out on the basis of this theory have had tremendous influence on the development of the field. This issue has been frequently discussed and studies have been carried out especially in the regions where uncertainties are intense. Somehow, this study did not come to Turkey in the level of air transportation and was stayed on level of the modes of logistics which is road transportation . As in studies carried out on aircraft selection problems, there is exist a significant gap on design of the flight network in Turkey. This is another of the executive powers of the thesis. Thence, an aircraft selection procedure was proceed by using geographic and financial constraints for a regional airline which planned to operate in Turkey were carried out. Required data to create the constraints were collected from the leaflets on the web pages of each aircraft manufacturer. Geographical constraints have been achieved through Google Maps. Data needed for the design of the flight network were also carried out following the previous procedure. In addition, the data published by the Turkish statistical institute were used as a complementary data of General Directorate of Turkish Civil Aviation Authority .

CHAPTER 4

AIRCRAFT SELECTION PROBLEM

The airline industry is one of the most competitive sectors. The balance between supply and demand is directly related to the efficient and efficient use of resources by airlines in cases where the high passenger capacity remains low. One of the most critical issues is the proper planning of the fleet and the selection of the appropriate aircraft type for the airlines that are forced to use their existing resources effectively and efficiently in the competitive environment. In other words, the fact that airlines act according to many criteria in selecting aircraft and choosing the right aircraft may enable it to gain strategic competitive advantage over other airlines. Therefore, accurate determination of which type of aircraft is the most suitable aircraft according to their needs may pave the way for lower cost and higher potential.

Airline companies having the right fleet structure and choosing the type of aircraft in an appropriate way can also adapt to the changing market conditions more quickly and reach the appropriate solutions to meet the needs. Airline companies make the right choice of the most suitable aircraft type among the aircraft alternatives by taking into consideration a number of evaluation criteria together, enabling the efficient use of the resources owned by the sector as well as the efficient and efficient use of environmental and economic resources. This also paves the way for firms to make the right choice among many criteria such as capacity, speed, performance, profitability and cost.

Study consists of 5 different methods. As a continuation of the study, the characteristics of low cost airline carriers will be introduced in order to base the selection of aircraft type. In the third part of the study, AHP, TOPSIS, PROMETHEE, ELECTRE I and VIKOR methods, which are preferred multi-criteria decision making methods, will be introduced in detail. In the last part of the study, information about the criteria and aircraft types will be given and the empirical application of the study will be given. In the last part of the study, the findings will be presented.

4.1 Characteristics of Low Cost Carriers

In the literature, low-cost carriers are named by many different names. These include low-price carriers / budget carriers, budget airlines, no-frills carriers, and more. We prefer low cost carriers. From the customer's point of view, customers use the term 'low-fare' instead of 'low-cost', because they are interested in the prices they offer, not the costs of airline companies, and therefore easier to name and remember airline business [81]. Although there is no specific definition for low-cost carriers, the common features for low-cost carriers generally define the concept of low-cost carriers. Accordingly, it is generally possible to identify low-cost carriers in light of the following six principles;

- Intensive use of aircraft,
- Standardized fleet structure,
- Low ticket prices,
- Reduced costs through abolition of non-revenue generating services
- Direct flight from point to point at short distance,
- Reduced labor per aircraft.

4.1.1 The Most Determining Properties of Low Cost Carriers

Low cost carriers, have tendency on a simplified price policy [82]. For example, in the United States, Southwest Airlines has played a major role in lowering ticket prices from liberalization to the present, offering the lowest price on almost all flights. The following statements are interesting as low-cost carriers are an extreme example of price policy. According to Roy Spence, president of one of Southwest Airlines 's advertising agencies, Herb Kelleher, the president of Southwest Airlines, has always had a populist approach to managing Southwest Airlines, and instead of filling half the plane with a $ 200 ticket price, it's worth for $ 49 preferred to fill it all [83].

Although low-cost carriers try to have a simple and easy-to-understand pricing policy, in Europe, unlike Southwest Airlines, which they take as an example in the United States, they apply revenue management based on raising prices as flight dates approach and aircraft occupancy increases. Thus, it is impossible to find tickets at an unbelievably low price, which they had originally announced and initially sold and also saw as a marketing tool. In contrast, Southwest Airlines prefers a single, fixed price policy.

4.1.2 Inflight Services

Many services provided during the flight in low cost carriers limited and even removed. This method saves labor and costs. In this way, the time to prepare for flight after landing was also shortened. Drinks served on board are also usually paid, and revenue is generated in this way. However, some low-cost carriers, such as Debonair, also contribute to reducing costs by choosing to offer less catering rather than non-catering [82]. If a passenger wants to eat and drink during the flight, he / she can receive such services by paying on board. In this way, low-cost carriers earn revenue from such sales on board and contribute to reducing costs.

4.1.3 Direct Ticket Sales And Reservation

Another cost-saving feature of low-cost carriers is that they do not have ticket sales offices in the cities where they serve and do not pay commissions to travel agencies and intermediaries. For this reason, direct sales through internet and telephone are encouraged. Selling through the internet, which is a cheap ticketing method, has become a method of choice for most low cost carriers. However, low cost carriers who use the phone to sell tickets to people who do not have an internet connection do not sell their tickets as cheaply as they do on the internet. Because it is an expensive method of selling by phone compared to the internet.

The Internet is also the fastest, easiest and cheapest way to provide information to passengers. Passengers are informed about tax-related information and conditions. They can also quickly and easily access information on many flights and prices.

4.1.4 Aircraft Utilization And Capacity

One of the common characteristics of low-cost carriers is perhaps the high rate of use of aircraft. This is achieved by shortening the waiting time of the aircraft on the ground. Southwest Airlines is in the lead in the short period of waiting times of the planes on the ground and consequently during daily use hours. At the same time, low-cost carriers maximize aircraft capacity by opting for a single-class, which is economy-only, aircraft cabin arrangement rather than a business or first-class aircraft layout options. In fact, they increase the passenger capacity of the aircraft by reducing the space between seats in a single-class aircraft layout. This results in a lower value of the break-even point. Therefore, increasing the number of seats is one of the important points in reducing costs and reducing prices.

4.1.5 Use Of Secondary Airports

Most of the low-cost carriers prefer secondary airports for cost advantages and faster return. The use of secondary airports not only contributes to lower airport fees, but also contributes to a shorter return time due to the small crowd. Low cost carriers generally prefer secondary airports that are further away from the city. However, EasyJet, which stands out as an exception, also travels to primary airports, which are mostly used by business travelers.

4.1.6 Short Distance Direct Flights

Low cost carriers usually serve as point-to-point flight over short distances. Low-cost carriers flying at short distances also consisted of Boeing 737 and Airbus 319-320 type aircraft, which can also fly at short distances. Looking at the routes that low-cost carriers in Europe fly, it is often observed that they do not fly far beyond the European continent and even to relatively remote routes in the east and southeast of Europe.

Low cost carriers prefer direct point-to-point direct flight between the two cities, rather than the hub and spoke system, which serves long-distance flights to the final destination from the large, central airports, which are preferred by traditional carriers. This is more in line with the low-cost carrier strategy. This will increase the cost of low-cost carriers as the time that the aircraft will spend on the ground due to the expectation of the passengers coming from the connecting places and consequently the usage period of the aircraft will decrease and the fees to be paid to the airport will increase [84].

4.1.7 Fleet Similarity

Low cost carriers generally follow the path of having a uniform aircraft in their fleet. The first is to reduce maintenance, training and spare parts inventory costs, the second is to have greater flexibility in cockpit personnel planning and fleet management, and the third is to reduce the purchase costs of aircraft. Herb Kelleher, president of Southwest Airlines, now the 4th largest fleet in the United States, has implemented a single-fleet model for the first time [85].

4.1.8 Other Factors

Low-cost carriers can do some of their services and also they follow the way of take services by outsourcing. This increases productivity and provides significant reductions in costs. Unlike traditional carriers, low-cost carriers purchase most of the passenger services and aircraft ground handling activities at airports, and tend to have only minimal staff in such tasks.

At the same time, in connection with the outsourcing of many activities, low-cost carriers do not employ a large number of administrative personnel, such as conventional planning and bilateral agreement personnel, at traditional headquarters. It works flexibly with a small number of personnel, and one staff member can undertake the tasks of more than one staff in traditional carriers.

This type of air transportation can save everyone budget also make contribution of reduction of cost of service, but it also fosters the consumption economy. Although LCC's are economic and efficient way of transportation in airline industry, most of passengers thought that it is not environmentally and economically sustainable. In this context, Sarker et al. conducted a survey which reveals that airlines customers' current perception on LCC’s and future expectations about it [86]. According to study, most of the attendant thinking that low cost carrier concept is not so proper way to ensure environmentally safe transportation creation. Comprehensive research diagram is also shown in the Figure 4.1.

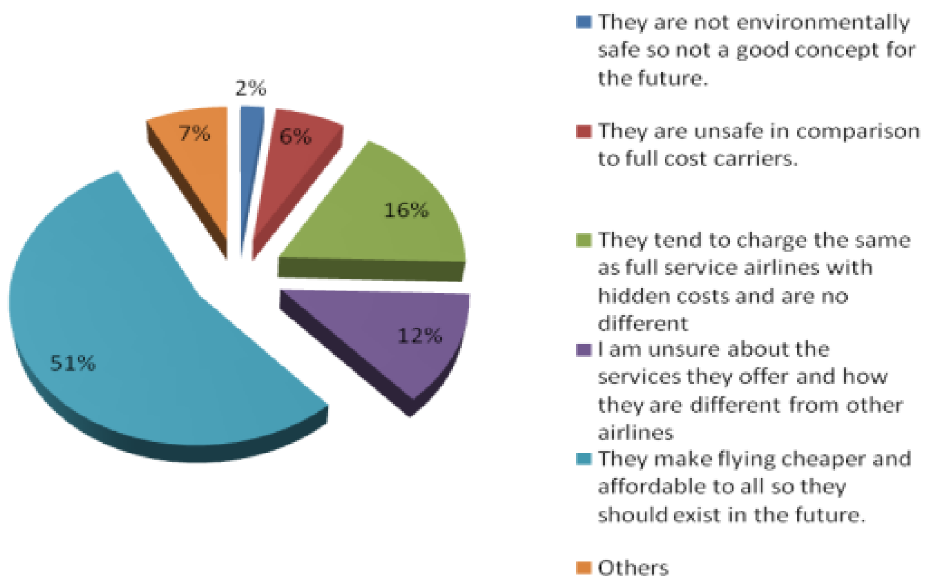


Figure 4.1 Perception of current LCC's and future expectations

In addition, business travel, which occupies an important place in air transport, has led to the emergence of various concepts in this field. This is because many airline companies sell pre-booked tickets for managers and directors of industrial companies, and are making a significant contribution to increasing occupancy rates of aircrafts. This circumstance makes business trips less of a concern. On the other hand, the fact that the business trips are long or short distance brings a significant difference in the price of the tickets that the companies want to buy. These reasons and many more increase the demand for low cost airlines because in short-distance trips, the amount of allowance granted by the companies to the traveler decreases [87]. This situation was examined by Mason and the results were explained in the Figure 4.2.

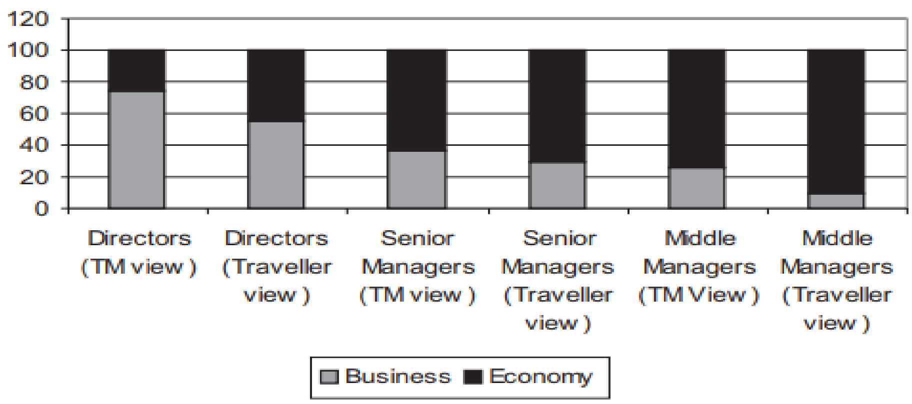


Figure 4.2 Short haul travel class allowance

4.2 Aircraft and Criterion Determination

Based on the information presented on other factors section, it was decided which criteria should be determined in order to use multi-criteria decision making methods. As mentioned in the literature review, many studies have been used to determine the technical and financial features of the aircraft. However, financial constraints do not produce realistic results as the value of money varies frequently between countries and varies according to variations of aircraft. Therefore, the criteria selected for the aircraft selection procedure were established using the technical characteristics of the aircraft based on cost issues. The specified criteria are listed below.

1. Maximum take-off weight (MTOW)
2. Range (kilometers)
3. Fuel capacity (liters)
4. Passenger capacity
5. Maximum cruise speed (km/h)
6. Fuel consumption (kg/seat km)

Necessary data were obtained from the technical booklets of the nominated aircraft and from the manufacturers' web sites. In order to determine the list of candidate aircrafts, the aircrafts used by many low cost airlines in their fleet have been examined.

Table 4.1 World's best low-cost airlines

Rank	Airline
1	AirAsia
2	EasyJet
3	Norwegian
4	Southwest Airlines
5	AirAsia X
6	Jetstar Airways
7	WestJet
8	IndiGo
9	Ryanair
10	Eurowings

The airlines reviewed were selected by Skytrax from the list of the best low-cost carrier airlines published each year. According to the list world’s best low-cost airlines in 2019 are shown Table 4.1. In addition, the fleets of these airlines were examined and tabulated with respect to aircraft types.

Table 4.2 World top 10 low cost carriers' fleet intensity

Rank	Airline	Fleet Members
1	AirAsia	A320-A321
2	EasyJet	A319 - A320
3	Norwegian	B737-800
4	Southwest Airlines	B737(800-MAX)
5	AirAsia X	A330
6	Jetstar Airways	A320
7	WestJet	B737
8	IndiGo	A320
9	Ryanair	B737-800
10	Eurowings	A319 - A320

When fleet type it's intensity are examined, it is seen that the fleets are formed by Airbus A319, A320 and Boeing 737-800, 737 MAX and variations of these aircraft. Therefore, the list of candidate aircraft created was selected from the types of aircraft mentioned earlier and their possible competitors. While creating a list of candidate airplanes, different types of airplanes have been tried to be used and efforts have been made to reach different solutions. The list of candidate aircraft created is given below and shown in Table 4.2;

- Airbus A220
- Airbus A320-NEO
- Boeing B737-800
- Boeing B737 MAX 8
- Bombardier CRJ900
- Bombardier CRJ1000
- Embraer E175

- Embraer E190
- Embraer E195
- Sukhoi SSJ00

Thus, criteria for the evaluation of candidate aircraft and aircraft were selected and the data set was prepared. In the following sections of the study, AHP, TOPSIS, PROMETHEE, ELECTRE and VIKOR methods and decision making process with these methods are explained in a sequence. Methods used are explained in as simple and understandable language as possible.

4.3 Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was first introduced by Myers and Alpert in 1968, and in 1977 Saaty developed it as a model and made it available to solve decision-making problems. AHP can be explained as a decision making and estimation method used in case the decision hierarchy can be defined, which gives the percentage distributions of decision points in terms of the factors affecting the decision. AHP is based on one-to-one comparisons on a decision hierarchy, using a predefined comparison scale, both in terms of the factors affecting the decision and the significance of the decision points in terms of these factors. As a result, differences in importance turn into percentage distribution over decision points. The steps to be taken in order to solve a decision-making problem with AHP are described below. At each step, explanations were made with the formulation.

Step 1: Identify the Decision Making Problem

The definition of the decision-making problem consists of two stages. In the first stage, decision points are determined. In other words, the answer to the question of how many results will be evaluated is sought. In the second stage, the factors affecting the decision points are determined. In this study, the number of decision points is symbolized by m and the number of factors affecting decision points is symbolized by n. Particularly, the correct determination of the number of factors that will affect the outcome and the detailed definitions of each factor are important in terms of making consistent and logical binary comparisons.

Step 2: Create an Inter-Factor Comparison Matrix

The inter-factor comparison matrix is a dimensional square matrix. The matrix components on the diagonal of this matrix take the value 1. The comparison matrix is shown below.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

The components on the diagonal of the comparison matrix, that is, take the value 1. So in this case the relevant factor is compared with itself. The comparison of the factors is made one-to-one and reciprocal according to their importance values relative to each other. Factor scale in Table 4.3 is used for one-to-one comparison of factors.

Table 4.3 Factor scale

Importance Values	Value Description
1	Equal importance of both factors
3	Factor 1 is more important than factor 2
5	Factor 1 is much more important than factor 2
7	Factor 1 has a very strong importance compared to factor 2
9	Factor 1 is of absolute superiority compared to factor 2
2,4,6,8	Intermediate values

For example, if the first factor appears to be more important than the fourth factor by the comparator, then the first row fourth column component of the comparison matrix (i = 1, j = 4) will take the value 3. Otherwise, if the more important preference is to be used in the comparison of the first factor with the third factor, then the first row of the comparison matrix in Table 4.4 will take the value of 1/3 of the third column component.

Table 4.4 Decision matrix

TYPE	MTOW	RANGE	FC	PC	MCS	FUEL CONS.
A220	63,1	6297	21805	120	829	0,0289
A320-Neo	73,5	6300	26730	180	840	0,0403
B737-800	79	5665	26020	160	946	0,0383
B737 Max 8	82,1	6570	25941	162	975	0,0354
CRJ900	38,3	2871	8890	90	871	0,0749
CRJ1000	39	3056	8890	104	871	0,0749
E175	40,4	4074	9335	88	871	0,0633
E190	51,8	4537	12971	114	871	0,0564
E195	52,3	4260	12971	124	871	0,0564
SSJ100	49,5	4578	15805	108	860	0,0589

In the same comparison, if the first factor and the third factor are used in preference to the fact that the factors are of equal importance, then component 1 will be taken.

Comparisons are made for values that lie above the diagonal of all values of the comparison matrix. For the components under the diagonal, it is natural to use the Eq. 4.1

$$a_{ji} = \frac{1}{a_{ij}} \quad (4.1)$$

If the example given above takes into account the first row fourth column component of the comparison matrix (i = 1 j = 4) 3, the fourth row first column component of the comparison matrix (i = 4, j = 1) will take 1/3 from Eq. 4.1 in Table 4.5.

Table 4.5 Scaled comparison matrix

	MTOW	RANGE	FUELCAP	PASS	CRUISE	CONSP.
MTOW	1,000	0,333	1,000	1,000	1,000	0,200
RANGE	3,000	1,000	2,000	5,000	9,000	1,000
FUELCAP	1,000	0,500	1,000	2,000	5,000	0,500
PASS	1,000	0,200	0,500	1,000	2,000	0,333
CRUISE	1,000	0,111	0,200	0,500	1,000	0,143

CONSP.	5,000	1,000	2,000	3,000	7,000	1,000

The comparison matrix shows the importance levels of factors relative to each other in a particular logic. However, in order to determine the weights of these factors in the whole, in other words, percent significance distributions, column vectors forming the comparison matrix are used and column B with n and n components is formed. This vector is shown below:

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix}$$

Equation 4.2 is used in the calculation of column B vectors.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{4.2}$$

When the steps described above are repeated in other evaluation factors, the column number B will be the same as the number of factors. When the B column vectors are combined in a matrix format, the C matrix shown below will be formed.

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix}$$

Table 4.6 Column normalized matrix

	MTOW	RANGE	FUELCAP	PASS	CRUISE	CONSP.
A220	0,1109	0,1306	0,1288	0,0960	0,0942	0,0548
A320-Neo	0,1292	0,1307	0,1578	0,1440	0,0954	0,0764
B737-800	0,1388	0,1175	0,1536	0,1280	0,1074	0,0726
B737Max8	0,1443	0,1363	0,1532	0,1296	0,1107	0,0671
CRJ900	0,0673	0,0596	0,0525	0,0720	0,0989	0,1419
CRJ1000	0,0685	0,0634	0,0525	0,0832	0,0989	0,1419
E175	0,0710	0,0845	0,0551	0,0704	0,0989	0,1200
E190	0,0910	0,0941	0,0766	0,0912	0,0989	0,1069
E195	0,0919	0,0884	0,0766	0,0992	0,0989	0,1069
SSJ100	0,0870	0,0950	0,0933	0,0864	0,0977	0,1116

By using the C matrix, the percent significance distributions showing the importance values of the factors relative to each other can be obtained as in Table 4.6. For this purpose, as shown in Equation 4.3, the arithmetic mean of the row components constituting the C matrix is obtained and the column vector W called the Priority Vector is obtained as shown in Figure 4.3.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{4.3}$$

Category		Priority	Rank	(+)	(-)
1	MTOW	8.6%	4	3.6%	3.6%
2	RANGE	32.4%	1	5.8%	5.8%
3	FUELCAP	15.2%	3	4.3%	4.3%
4	PASS CAP	8.1%	5	1.3%	1.3%
5	CRUISE	4.6%	6	1.9%	1.9%
6	CONSP	31.1%	2	5.9%	5.9%

Figure 4.3 Priorities of criteria

Step 4: Measure Consistency between Factor Benchmarking

Although AHP has a consistent systematic in itself, the realism of the results will naturally depend on the consistency in the one-to-one comparison between the decision-making factors. AHP proposes a process for measuring the consistency of these comparisons. With the resulting Consistency Ratio (CR), it is possible to test the consistency of the found priority vector and thus one-to-one comparisons between factors. The essence of the CR calculation is based on a comparison of the number of factors and a coefficient called the Basic Value (lambda). However, this test is not mandatory.

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

As defined in Equation 4.4, the base value E for each evaluation factor is obtained from the part of the opposing elements of the column vector D and the column vector W found. The arithmetic mean of these values (Eq. 4.5) gives the basis of comparison (λ).

$$E_i = \frac{d_i}{w_i} \qquad (i = 1,2,\dots,n) \tag{4.4}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{4.5}$$

After lambda is calculated, the Consistency Indicator (CI) can be calculated using the formula .

$$CI = \frac{\lambda - n}{n-1} \tag{4.6}$$

In the last step, the CI is divided by the standard correction value called Random Indicator (RI) and shown in Equation 4.6 to obtain CR. The value corresponding to the number of factors is selected from Table 4.7. For example, the RI value to be used in a 6-factor comparison would be 1.24 from Table 4.7.

Table 4.7 Randomness index

N	RI	N	RI
1	0	**8**	1,41
2	0	**9**	1,45
3	0,58	**10**	1,49
4	0,9	**11**	1,51
5	1,12	**12**	1,48
6	1,24	**13**	1,56

$$CR = \frac{CI}{RI} \quad (4.7)$$

If the calculated CR value is less than 0.10, the comparisons made by the decision maker are consistent. If a CR value greater than 0.10 indicates either a calculation error in AHP or inconsistency in decision-making comparisons. In this study CR value calculated as %3.4 which is lower than %10 so calculation is consistent as shown in Figure 4.4.

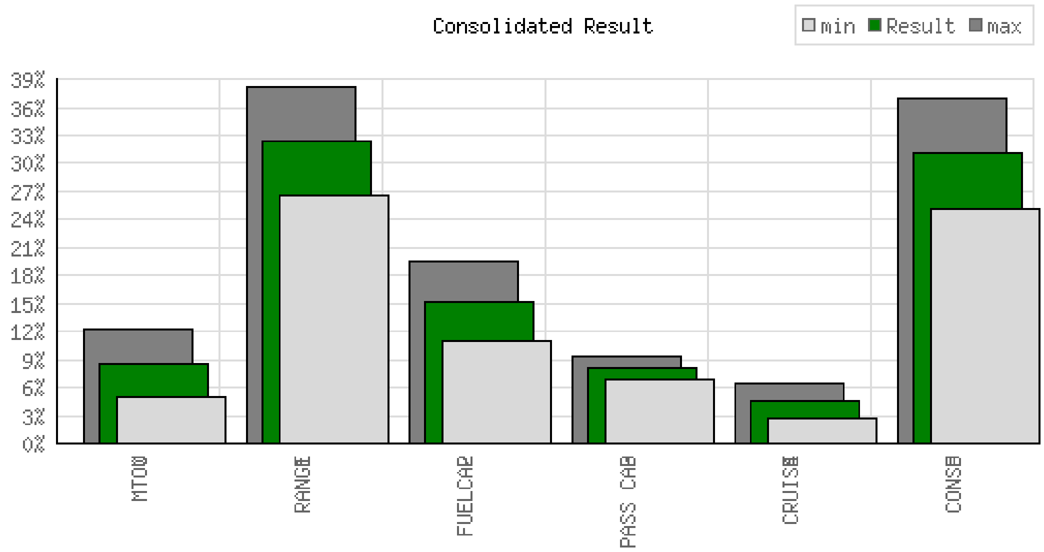


Figure 4.4 Consolidated priorities due to consistency index

Step 5: Find Percentage Importance at each Decision Point for each Factor

This stage is determined as above, but this time, the percent significance distributions of the decision points for each factor. In other words, one-to-one comparisons and matrix operations are repeated for the number of factors (n times).

However, this time the size of the G comparison matrices to be used in the decision points for each factor will be MxM. After each comparison process, S column vectors are obtained which show the dimensional and percentage distributions of the factor evaluated according to the decision points.

$$S_i = \begin{bmatrix} s_{11} \\ s_{21} \\ . \\ . \\ . \\ s_{m1} \end{bmatrix}$$

Step 6: Finding Outcome Distribution at Decision Points

At this stage, first of all, the mxn size K decision matrix consisting of n mx1 dimensional S column vectors described above is created. The decision matrix is described in Table 4.4.

$$K = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1n} \\ s_{21} & s_{22} & \dots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \dots & s_{mn} \end{bmatrix}$$

As a result, when the decision matrix W column vector (priority vector) is multiplied, column L with m elements is obtained. Column L gives the percentage distribution of decision points. In other words, the sum of the elements of the vector is 1. This distribution also shows the order of importance of the decision points.

$$L = \begin{bmatrix} s_{11} & s_{12} & \ldots & s_{1n} \\ s_{21} & s_{22} & \ldots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \ldots & s_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = \begin{bmatrix} l_{11} \\ l_{21} \\ . \\ . \\ . \\ l_{m1} \end{bmatrix}$$

The processes mentioned in the study were carried out meticulously and the results were obtained at the end of the process. All processes are explained as simple as possible to avoid confusion. Not all Tables created during the process are given. this is because it is difficult to understand the complex sequence of numbers resulting from many normalized numbers.

Table 4.8 Final decision scores

Aircraft	Score
A220	0,1005369
A320-Neo	0,1172266
B737-800	0,1112411
B737 MAX 8	0,1162871
CRJ900	0,0876112
CRJ1000	0,089868
E175	0,0894308
E190	0,0951482
E195	0,0940141
SSJ100	0,0986361

According to final decision matrix highest rank taken by Airbus A320 NEO is recommended for creation a domestic low cost carrier fleet shown in Table 4.8.

4.4 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Yoon and Hwang in 1980 and uses the basic approaches of the ELECTRE method. The closeness of decision points to the ideal solution is based on the main principle and the solution process is shorter than the ELECTRE method. The TOPSIS method involves a 6-step solution process. The first two steps of the method are common to the ELECTRE method. The steps of the TOPSIS method are described below.

Step 1: Formation of Decision Matrix (A)

In the lines of the decision matrix, there are decision points whose superiorities are to be listed and in the columns, evaluation factors to be used in decision making. Matrix A is the initial matrix created by the decision maker. The decision matrix is shown as follows:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

In Aij matrix, m gives the number of decision points and n gives the number of evaluation factors. Initial Aij matrix is same with AHP method.

Step 2: Creating the Standard Decision Matrix (R)

Standard Decision Matrix is calculated using the elements of matrix A and using the following formula and shown in Table 4.9.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{4.8}$$

After this process R matrix is obtained as following,

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

Table 4.9 Real standard decision matrix

TYPE	MTOW	RANGE	FC	PC	MCS	FCONS
A220	0,3380	0,3995	0,3755	0,2951	0,2974	0,1662
A320-Neo	0,3937	0,3997	0,4604	0,4427	0,3013	0,2318
B737-800	0,4232	0,3594	0,4481	0,3935	0,3393	0,2203
B737 MAX 8	0,4398	0,4168	0,4468	0,3984	0,3498	0,2036
CRJ900	0,2052	0,1821	0,1531	0,2213	0,3124	0,4307
CRJ1000	0,2089	0,1939	0,1531	0,2558	0,3124	0,4307
E175	0,2164	0,2585	0,1608	0,2164	0,3124	0,3640
E190	0,2775	0,2878	0,2234	0,2804	0,3124	0,3243
E195	0,2801	0,2703	0,2234	0,3050	0,3124	0,3243
SSJ100	0,2651	0,2904	0,2722	0,2656	0,3085	0,3387

Step 3: Creating the Weighted Standard Decision Matrix (V)

Weight values (w_i) for evaluation factors should be determined firstly. ($\sum_{i=1}^{n} w_i = 1$).

Then the elements in each column of the matrix R are multiplied by the corresponding w_i value to form the V matrix. The V matrix is shown below:

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix}$$

Step 4: Creating Ideal (A *) and Negative Ideal (A-) Solutions

The TOPSIS method assumes that each evaluation factor has a monotonous increasing or decreasing trend. In order to create an ideal solution set, the largest of the weighted evaluation factors in the V matrix (i.e. the smallest if the corresponding evaluation factor is minimized) is selected. Finding the ideal solution set is shown in the following formula.

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J^{'} \right\} \quad (4.9)$$

The set to be calculated from Equation 4.9 is indicated by $A^* = \{v_1^*, v_2^*, ..., v_n^*\}$. Set of negative ideal solutions are formed by selecting the smallest of the weighted evaluation factors in the V matrix, namely the column values (the largest if the corresponding evaluation factor is maximized). Finding the negative ideal solution set is shown in the following equation.

$$A^- = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J^{'} \right\} \quad (4.10)$$

Set to be calculated from Equation 4.10 can be shown as $A^- = \{v_1^-, v_2^-, ..., v_n^-\}$.Both formulas show the benefit (maximization) and the loss (minimization) value. The ideal and negative ideal solution set consists of the number of evaluation factors, namely m elements and shown in Table 4.10.

Table 4.10 Weighted standard decision matrix and ideal solutions

TYPE	MTOW	RANGE	FC	PC	MCS	FCONS
A220	0,0291	0,1294	0,0571	0,0239	0,0057	0,0517
A320-Neo	0,0339	0,1295	0,0700	0,0359	0,0057	0,0721
B737-800	0,0364	0,1164	0,0681	0,0319	0,0064	0,0685
B737 MAX 8	0,0378	0,1350	0,0679	0,0323	0,0066	0,0633
CRJ900	0,0176	0,0590	0,0233	0,0179	0,0059	0,1340
CRJ1000	0,0180	0,0628	0,0233	0,0207	0,0059	0,1340
E175	0,0186	0,0837	0,0244	0,0175	0,0059	0,1132
E190	0,0239	0,0933	0,0340	0,0227	0,0059	0,1009
E195	0,0241	0,0876	0,0340	0,0247	0,0059	0,1009
SSJ100	0,0228	0,0941	0,0414	0,0215	0,0059	0,1053
A*	0,0378	0,1350	0,0700	0,0359	0,0066	0,0517
A-	0,0176	0,0590	0,0233	0,0175	0,0057	0,1340

Step 5: Calculation of Discrimination Measures

In the TOPSIS method, Euclidian Distance Approach is used to find the deviations of the evaluation factor value for each decision point from the ideal and negative ideal solution set. Deviation values for the decision points obtained here are called Ideal Discrimination (S_i^*) and Negative Ideal Discrimination (S_i^-) Measure. Calculation of the ideal discrimination (S_i^*) measure is shown in Eq. 4.11 and the calculation of the negative ideal discrimination (S_i^-) measure is shown in Eq. 4.12

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \qquad (4.11)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \qquad (4.12)$$

Number of S_i^* and S_i^- to be calculated here will naturally be the number of decision points.

Step 6: Calculating Proximity to the Ideal Solution

Ideal and negative ideal discrimination measures are used to calculate the proximity (C_i^*) of each decision point relative to the ideal solution. Criterion used here is the share of the negative ideal discrimination measure within the total discrimination measure. The calculation of the proximity to the ideal solution is shown in the following formula.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \qquad \text{Equation (4.13)}$$

Here, the value C_i^* takes a value in the range of $0 \le C_i^* \le 1$ and $C_i^* = 1$ indicates the absolute proximity of the respective decision point to the ideal solution, and $C_i^* = 0$ indicates the absolute proximity of the corresponding decision point to the negative ideal solution.

Table 4.11 Ideal solution proximity

	A220	**A320 NEO**	**B737 800**	**B737 Max8**	**CRJ 900**	**CRJ 1000**	**E175**	**E190**	**E195**	**SSJ100**
S^{i*}	0,020	0,022	0,025	0,012	0,124	0,122	0,096	0,076	0,079	0,076

S_i^-	0,114	0,108	0,101	0,116	0,000	0,005	0,032	0,049	0,046	0,049
C_i^*	0,848	0,833	0,798	0,904	0,004	0,039	0,252	0,393	0,367	0,392

According to the results obtained from the TOPSIS method presented on Table 4.11, the alternative with the highest Ci value is the most appropriate alternative. As shown in Table 4.11, Boeing 737 Max8 is the most appropriate alternative to choose according to this method.

4.5 Elimination and Choice Translating Reality English (ELECTRE I) Method

ELECTRE method is a multiple decision making method which was first introduced by Beneyoun in 1966. The method is based on binary superiority comparisons between alternative decision points for each assessment factor. The method goes into solution in 8 steps [88]. The first 3 steps of this method are the same as the TOPSIS method, but the process differs from the other steps. Therefore, first 3 steps of the method are not explained in order not to encounter concept repetitions. Details can be seen on TOPSIS method. Rest steps of ELECTRE method are described below.

Step 1: Formation of Decision Matrix (A)

Step 2: Creating the Standard Decision Matrix (X)

Step 3: Creating the Weighted Standard Decision Matrix (Y)

Step 4: Identify Concordance (C_{kl}) and Discordance (D_{kl}) Sets

Y matrix is used to determine the fit sets, the decision points are compared with each other in terms of evaluation factors and the sets are determined by the relationship shown in the following formula:

$$C_{kl} = \{j, y_{kj} \geq y_{lj}\} \tag{4.14}$$

The formula is basically based on the comparison of the size of the row elements relative to each other. The number of concordance sets in a multiple decision problem is determined as ($m.m-m$) because the k and l indices should be $k \neq l$ when creating fit sets. The number of elements in a fit set can be the maximum number of evaluation factors (n).

In the ELECTRE method, each concordance set (C_{kl}) shown in Table 4.12 corresponds to a set of discordance (D_{kl}) shown in Table 4.13. In other words, there are as many discordance sets as the number of concordance sets. The discordance set elements consist of j values that do not belong to the corresponding concordance set.

Step 5: Creating Concordance (C) and Discordance Matrices (D)

Concordance sets are used to form the concordance matrix (C). The matrix C is mxm and does not take any value for k = l. The elements of the matrix C are calculated using the relationship shown in the following formula.

$$c_{kl} = \sum_{j \in C_{kl}} w_j \tag{4.15}$$

Table 4.12 Concordance matrix

a/b	A220	A320 Neo	B737 800	B737 Max8	CRJ 900	CRJ 1000	E175	E190	E195	SSJ 100
A220	1,000	1,000	0,676	1,000	0,357	0,357	0,357	0,357	0,438	0,357
A320Neo	0,000	1,000	0,132	0,456	0,357	0,357	0,357	0,357	0,357	0,357
B737800	0,324	0,868	1,000	0,537	0,311	0,311	0,311	0,311	0,311	0,311
B737M8	0,000	0,544	0,463	1,000	0,311	0,311	0,311	0,311	0,311	0,311
CRJ900	0,643	0,643	0,689	0,689	1,000	1,000	0,608	0,689	0,689	0,643
CRJ1000	0,643	0,643	0,689	0,689	0,509	1,000	0,608	0,689	0,689	0,643
E175	0,643	0,643	0,689	0,689	0,438	0,438	1,000	0,689	0,689	0,643
E190	0,643	0,643	0,689	0,689	0,357	0,357	0,357	1,000	0,676	0,787
E195	0,562	0,643	0,689	0,689	0,357	0,357	0,357	0,833	1,000	0,787
SSJ100	0,643	0,643	0,689	0,689	0,357	0,357	0,357	0,213	0,213	1,000

The elements of the discordance matrix (D) are calculated using the following formula:

$$d_{kl} = \frac{\max_{j \in D_{kl}} \left| y_{kj} - y_{lj} \right|}{\max_{j} \left| y_{kj} - y_{lj} \right|} \tag{4.16}$$

Table 4.13 Discordance matrix

a/b	A220	A320 Neo	B737-800	B737 Max8	CRJ 900	CRJ 1000	E175	E190	E195	SSJ 100

A220	0,000	0,276	0,236	0,232	0,002	0,002	0,002	0,002	0,002	0,002
A320Neo	0,000	0,000	0,006	0,015	0,002	0,002	0,002	0,002	0,002	0,001
B737800	0,035	0,040	0,000	0,051	0,000	0,000	0,000	0,000	0,000	0,000
B737Max8	0,000	0,044	0,004	0,000	0,000	0,000	0,000	0,000	0,000	0,000
CRJ900	0,724	1,000	0,960	0,956	0,000	0,010	0,067	0,229	0,229	0,388
CRJ1000	0,724	1,000	0,960	0,956	0,000	0,000	0,057	0,229	0,229	0,388
E175	0,699	0,975	0,935	0,931	0,000	0,001	0,000	0,204	0,204	0,363
E190	0,495	0,771	0,731	0,727	0,000	0,000	0,000	0,000	0,001	0,159
E195	0,495	0,771	0,731	0,727	0,000	0,000	0,000	0,016	0,000	0,159
SSJ100	0,336	0,612	0,573	0,568	0,001	0,001	0,001	0,001	0,001	0,000

Step 6: Formation of Concordance Superiority (F) and Discordance Superiority (G) Matrices

Concordance superiority matrix (F) is mxm dimensional and the elements of the matrix are obtained by comparing the concordance threshold value ($\underline{c}$) with the elements of the concordance matrix (c_{kl}). The compliance threshold value ($\underline{c}$) is obtained by the following formula

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \tag{4.17}$$

m indicates the number of decision points in the formula. The elements of the matrix F (f_{kl}) take either a value of 1 or 0, and there is no value because they show the same decision points on the diagonal of the matrix. If $c_{kl} \geq \underline{c} \Rightarrow f_{kl} = 1$ and if $c_{kl} < \underline{c} \Rightarrow f_{kl} = 0$. In this study, concordance threshold value is calculated as 0,626511. Discordance superiority matrix (G) is also mxm dimensional and formed in a similar way to the F matrix. The discordance threshold value ($\underline{d}$) is obtained by the following formula:

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{4.18}$$

The elements of the matrix G(g_{kl}) also take the value of 1 or 0 and show the same decision points on the diagonal of the matrix, so there is no value on it. If $d_{kl} \geq \underline{d} \Rightarrow$

$g_{kl} = 1$ and if $d_{kl} < \underline{d} \Rightarrow g_{kl} = 0$. In this study, discordance threshold value calculated as 0,247288.

Table 4.14 Concordance and discordance superiorities

	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
C12	0	0	0	0	0	1	**C310**	1	1	1	1	1	1
C13	0	1	1	1	0	0	**C45**	1	1	1	1	1	1
C14	0	0	1	0	0	0	**C46**	1	1	1	1	1	1
C15	1	1	1	1	1	1	**C47**	1	1	1	1	1	1
C16	1	0	0	0	0	0	**C48**	1	1	1	1	1	1
C17	1	0	0	1	0	0	**C49**	1	1	1	1	1	1
C18	1	0	0	0	0	0	**C410**	1	1	1	1	1	1
C19	1	1	0	0	0	0	**C56**	0	0	0	0	0	0
C110	1	0	0	1	1	1	**C57**	0	0	0	1	0	0
C23	0	1	1	1	0	0	**C58**	0	0	0	0	0	0
C24	0	0	1	1	0	0	**C59**	0	0	0	0	0	0
C25	1	1	1	1	0	1	**C510**	0	0	0	0	1	0
C26	1	1	1	1	0	1	**C67**	0	0	0	1	0	0
C27	1	1	1	1	0	1	**C68**	0	0	0	0	0	0
C28	1	1	1	1	0	1	**C69**	0	0	0	0	0	0
C29	1	1	1	1	0	1	**C610**	0	0	0	0	1	0
C210	1	1	1	1	0	1	**C78**	0	0	0	0	0	0
C34	0	0	1	0	0	0	**C79**	0	0	0	0	0	0
C35	1	1	1	1	1	1	**C710**	0	0	0	0	1	0
C36	1	1	1	1	1	1	**C89**	0	1	0	0	0	0
C37	1	1	1	1	1	1	**C810**	1	0	0	1	1	1
C38	1	1	1	1	1	1	**C910**	1	0	0	1	1	1
C39	1	1	1	1	1	1							

In Table 4.14 given in binary consists of 1 and 0 s. 1 indicates that the criterion is concordant and 0 indicates that it is discordant.

Step 7: Creating the Total Dominance Matrix (E)

Elements (e_{kl}) of the Total Dominance Matrix (E) are equal to the mutual product of the elements f_{kl} and g_{kl}, as shown in the following Table 4.15. Here, the matrix E is mxm dimensional depending on the C and D matrices and again consists of 1 or 0 values.

Table 4.15 Dominance (Outranking) matrix

a/b	A220	A320 NEO	B737 800	B737 Max8	CRJ 900	CRJ 1000	E175	E190	E195	SSJ 100
A220	0	1	1	1	0	0	0	0	0	0
A320Neo	0	0	0	0	0	0	0	0	0	0
B737800	0	1	0	1	0	0	0	0	0	0
B737	0	1	0	0	0	0	0	0	0	0
CRJ900	1	1	1	1	0	1	1	1	1	1
CRJ1000	1	1	1	1	0	0	1	1	1	1
E175	1	1	1	1	0	0	0	1	1	1
E190	1	1	1	1	0	0	0	0	1	1
E195	1	1	1	1	0	0	0	1	0	1
SSJ100	1	1	1	1	0	0	0	0	0	0

Step 8: Determining the order of importance of decision points

Rows and columns of the matrix E show the decision points. These rows and columns are sorted according to the values received and the best alternative to be decided is determined.

Table 4.16 Final ranking

Aircraft	Rank
A320-NEO	1
B737 MAX 8	2
B737-800	3
A220	4
SSJ100	5
E190	6
E195	6
E175	8
CRJ1000	9
CRJ900	10

According to this method, the aircraft selected for the fleet installation was determined as Airbus A320 NEO and final ranking is shown in Table 4.16.

4.6 VIKOR Method

The VIKOR method, first expressed by Opricovic[89], was introduced by Opricovic and Tzeng[90] in 2004 to solve multi-criteria decision-making problems. The meaning of VIKOR in linguistic terms is a multi-criteria optimization and consensus solution. The basis of the method is the creation of a conciliatory solution within the framework of alternatives and evaluation criteria. It is known that the solution found is the closest solution to the ideal solution.

In the method, it is possible to make the closest decision to the ideal solution under certain conditions by creating a multi-criteria ranking index for alternatives. By comparing the proximity values to the ideal alternative, the sequential order is achieved [91]. VIKOR method reaches a total of 5 steps. The initial set of alternatives and criteria used is the same as other methods.

Step 1: The best (fi *) and worst (fi-) values are determined for each evaluation criterion. if criterion i is a criterion in terms of value or in terms of “utility” (i = 1,2,… for n); fi * and fi- can be expressed in following formula and Table 4.17.

$$f_i^* = \max_j f_{ij} \quad f_i^- = \min_j f_{ij} \tag{4.19}$$

Table 4.17 Initial matrix of VIKOR

TYPE	MTOW	RANGE	FUEL CAP	PASS CAP	MCS	FUEL CONS.
A220	63	6297	21805	120	829	0,0289
A320-Neo	74	6300	26730	180	840	0,0403
B737-800	79	5665	26020	160	946	0,0383
B737 Max8	82	6570	25941	162	975	0,0354
CRJ900	38	2871	8890	90	871	0,0749
CRJ1000	39	3056	8890	104	871	0,0749
E175	40	4074	9335	88	871	0,0633
E190	52	4537	12971	114	871	0,0564
E195	52	4260	12971	124	871	0,0564
SSJ100	50	4578	15805	108	860	0,0589
WEIGHT	0,086	0,324	0,152	0,081	0,046	0,311
fi*	82	6570	26730	180	975	0,0289
fi-	38	2871	8890	88	840	0,0749

Step 2: Sj and Rj values are calculated for each evaluation unit and shown in Table 4.18. wi represents criteria weights.

$$S_j = \sum_{i=1}^{n} wi(f_i^* - fi_j)/((f_i^* - (f_i^-) \quad (4.20)$$

$$R_j = \max\left[w_i(f_i^* - f_{ij})/(f_i^* - f_i^-\right] \quad (4.21)$$

Table 4.18 Weighted evaluation matrix

TYPE	MTOW	RANGE	FUEL	PASS	MCS	FUEL
A220	0,0373	0,0239	0,0420	0,0535	0,0497	0,0000
A320-Neo	0,0169	0,0236	0,0000	0,0000	0,0460	0,0768
B737-800	0,0061	0,0793	0,0060	0,0178	0,0099	0,0633
B737 Max8	0,0000	0,0000	0,0067	0,0161	0,0000	0,0438
CRJ900	0,0860	0,3240	0,1520	0,0803	0,0354	0,3100
CRJ1000	0,0846	0,3078	0,1520	0,0678	0,0354	0,3100
E175	0,0819	0,2186	0,1482	0,0821	0,0354	0,2318
E190	0,0595	0,1781	0,1172	0,0589	0,0354	0,1853
E195	0,0585	0,2023	0,1172	0,0500	0,0354	0,1853
SSJ100	0,0640	0,1745	0,0931	0,0643	0,0392	0,2022
Si	0,0495	0,1532	0,0834	0,0491	0,0322	0,1609
Rj	0,0860	0,3240	0,1520	0,0821	0,0497	0,3100

Step 3: Calculate the Q_j values for each evaluation unit.

$$Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1-v)(R_j - R^*)}{R^- - R^*} \quad (4.22)$$

In Equation 4.23 each values refers as;

$$S^* = min_j S_j, \quad S^- = max_j S_j, \quad R^* = min_j R_j, \quad R^- = max_j R_j \quad (4.23)$$

Table 4.19 Total evaluation matrix

	Si	Ri	(q=0)	(q=0,25)	(q=0,5)	(q=075)	(q=1)
A220	0,034	0,034	-0,056	-0,038	-0,019	-0,001	0,017
A320-Neo	0,027	0,027	-0,082	-0,071	-0,060	-0,050	-0,039
B737-800	0,030	0,030	-0,070	-0,056	-0,042	-0,028	-0,014
B737 Max8	0,011	0,011	-0,141	-0,147	-0,152	-0,158	-0,164
CRJ900	0,165	0,165	0,419	0,571	0,724	0,877	1,029
CRJ1000	0,160	0,160	0,401	0,548	0,695	0,843	0,990
E175	0,133	0,133	0,304	0,424	0,544	0,664	0,784

E190	0,106	0,106	0,204	0,296	0,388	0,480	0,572
E195	0,108	0,108	0,213	0,307	0,402	0,496	0,590
SSJ100	0,106	0,106	0,206	0,298	0,390	0,483	0,575

v is the weight of the majority of the criteria, in other words maximum group benefit. The value of v represents the weight for the strategy that provides the maximum group benefit, while the value of (1-v) represents the weight of the minimum regret of the opposing viewers as shown in Table 4.19.

Step 4: The calculated values (Q_j, S_j, R_j) are sorted. The evaluation unit with the smallest Q_j value is expressed as the best option within the alternative group.

Step 5: Two conditions must be met for the result to be accepted as valid. Only in this way can the alternative with the minimum Q value be considered the best or most suitable presented on Table 4.20.

Table 4.20 Sorted evaluation matrix

	Si	**Ri**	**(q=0)**	**(q=0,25)**	**(q=0,5)**	**(q=075)**	**(q=1)**
A220	4	4	4	4	4	4	4
A320-Neo	2	2	2	2	2	2	2
B737-800	3	3	3	3	3	3	3
B737 Max 8	1	1	1	1	1	1	1
CRJ900	10	10	10	10	10	10	10
CRJ1000	9	9	9	9	9	9	9
E175	8	8	8	8	8	8	8
E190	5	5	5	5	5	5	5
E195	7	7	7	7	7	7	7
SSJ100	6	6	6	6	6	6	6

Condition 1 (C1) - Acceptable advantage: A condition that states that there is a significant difference between the best and the closest option.

$$Q(P2) - Q(P1) \geq D(Q)$$

In this inequality, P1 is the first best alternative with the lowest Q value, and P2 is the second best alternative. D (Q) = 1 / (j-1)). j indicates the number of units of evaluation. If the number of evaluation units is less than 4, D (Q) = 0.25 is taken [92].

Condition 2 (C2) - Acceptable stability: The alternative P1 with the best Q value must have achieved the best score in a small number of S and R values. If one of the two conditions specified cannot be met, the set of spatial solutions is recommended as follows:

- P1 and P2 alternatives if the second condition is not met,

- If condition 1 is not met, alternatives P_1, P_2,…, P_m are expressed considering the inequality Q (P_M) - Q (P_1) ≥ D (Q) [93].

Table 4.21 Condition check and result monitoring matrix

	Si	**Ri**	**(q=0)**	**(q=0,25)**	**(q=0,5)**	**(q=0,75)**	**(q=1)**
A220	4	4	4	4	4	4	4
A320-Neo	2	2	2	2	2	2	2
B737-800	3	3	3	3	3	3	3
B737 Max8	1	1	1	1	1	1	1
CRJ900	10	10	10	10	10	10	10
CRJ1000	9	9	9	9	9	9	9
E175	8	8	8	8	8	8	8
E190	5	5	5	5	5	5	5
E195	7	7	7	7	7	7	7
SSJ100	6	6	6	6	6	6	6
		Q(A1)	-0,14093	-0,1467	-0,15247	-0,15824	-0,16401
		Q(A2)	-0,08212	-0,07125	-0,06039	-0,04952	-0,03865
		DQ	0,111111	0,111111	0,111111	0,111111	0,111111
		Q(A2)-Q(A1)	0,05881	0,075446	0,092083	0,108719	0,125356
		CONDITION1	FALSE	FALSE	FALSE	FALSE	**TRUE**
		CONDITION2	TRUE	TRUE	TRUE	TRUE	**TRUE**

In Table 4.21, the values obtained by VIKOR method are listed. The conditions that must be met according to the listed values have been tested. As a result of the tests carried out, the exact solution for q = 1 provided all conditions. Under these conditions, the order given for q = 1 is considered to be the optimal and optimal solution.

4.7 PROMETHEE Method

The PROMETHEE (Preference Ranking Organization METHod for Encrichment Evaluations) method is a multi-criteria prioritization method developed by Brans [94] in 1982. Method consists of two main steps: PROMETHEE 1 (partial order) and PROMETHEE 2 (full order). The explanations of the PROMETHEE method are also compiled from Brans (1982). This method has been developed based on the difficulties of the existing prioritization methods in the literature and it has been used in some studies about various problems until today. In this study, plane selection problem has been handled by PROMETHEE method which is one of the efficient sorting methods and used in many sorting problems and an application has been made. The PROMETHEE method allows for more detailed analysis by evaluating alternatives on the basis of different preference functions and ensuring that both partial priorities and full priorities are achieved.

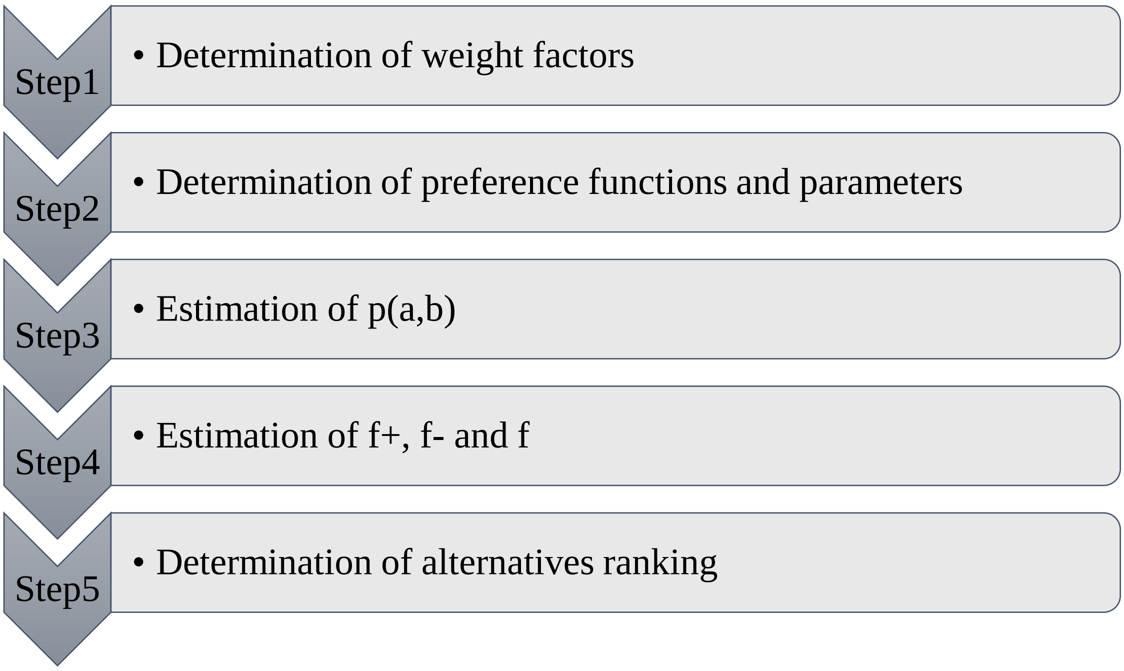


Figure 4.5 Flow diagram of PROMETHEE

Method determines the order of decision points in the main steps PROMETHEE 1 and PROMETHEE 2. PROMETHEE method is based on pairwise comparisons of decision points based on assessment factors. Main difference that distinguishes PROMETHEE from other multivariate decision-making methods is the importance weights of the evaluation factors showing each other and the internal relationship of each evaluation factor. Internal relationship of the evaluation factors is determined by the distribution of the data set and 6 different distributions are envisaged for this purpose. Method has 7 steps, from start to finish. Visual Promethee (1.4 Academic Edition) software was used while applying the method. Data obtained were also taken from the reporting part of the package program. Steps and the formulas of method contain are listed below and explained briefly. As a first step, the decision maker is asked to define the decision points and the evaluation factors. Then, the data sets are formed by determining the importance weights of the evaluation factors. The resulting data Table is the same as the initial matrix created in other methods. General Table is shown below.

		Criteria				
		f_1	f_2	f_3	---	$\boldsymbol{f_k}$
Decision Points	A	f_1 (A)	f_2 (A)	f_3 (A)	---	$\boldsymbol{f_k}$ **(A)**
	B	f_1(B)	f_2(B)	f_3(B)	---	$\boldsymbol{f_k}$ **(B)**
	C	f_1 (C)	f_2 (C)	f_3 (C)	---	$\boldsymbol{f_k}$ **(C)**
	---	---	---	---	---	---
Weights	$\boldsymbol{w_i}$	$\boldsymbol{w_1}$	$\boldsymbol{w_2}$	$\boldsymbol{w_3}$	---	$\boldsymbol{w_k}$

Figure 4.6 PROMETHEE initial table

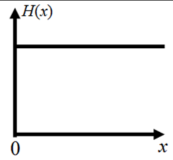
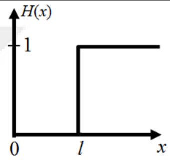
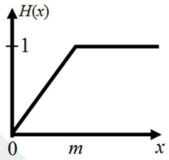
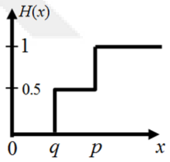
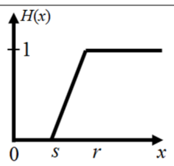
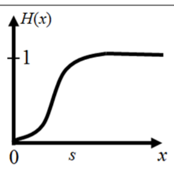
In second step, Preference functions are determined to show the structure and internal relationship of the assessment factors identified. There are six types of preference functions. These functions are shown in Table 4.23. This method does not determine an internal absolute benefit either on the basis of decision points and independently, neither for the whole nor for each assessment factor. Instead, it makes comparisons of decision points according to evaluation factors with binary comparisons. For this, it uses the preference functions defined in Table 4.22. Explanations of the values defined in Table 4.22 are as follows;

q: Indifference Value

p: Exact Choice Threshold

s: Intermediate value or Standard Deviation between p and q

Table 4.22 Preference funcion types

Types	Function	Shape
Type I (Usual)	$H(x_j)=\begin{cases}0, & x_j \le 0\\ 1, & x_j \ge 0\end{cases}$	
Type II (U-shape)	$H(x_j)=\begin{cases}0, & x_j \le l\\ 1, & x_j \ge l\end{cases}$	
Type III (V-shape)	$H(x_j)=\begin{cases}\frac{x}{m}, & x_j \le m\\ 1, & x_j \ge m\end{cases}$	
Type IV (Discrete)	$H(x_j)=\begin{cases}0, & x_j \le q\\ 1/2, & q < x_j \le p\\ 1, & x_j > p\end{cases}$	
Type V (Linear)	$H(x_j)=\begin{cases}0, & x_j \le s\\ (x-s)/r, & s < x_j \le r\\ 1, & x_j > r\end{cases}$	
Type VI (Gaussian)	$H(x_j)=\begin{cases}0, & x_j \le 0\\ 1-e^{-\frac{x_j^2}{2\sigma^2}} & x_j \ge 0\end{cases}$	

The value of q is the largest difference according to the decision points of the evaluation factors, while the value of p is the smallest difference. Decision maker will decide which preference function to choose for which evaluation factor. Again, the decision maker will make the determination by looking at the distribution of data related to a criterion when selecting this function. An important advantage of the PROMETHEE method over other multiple decision-making methods is that it allows the decision-maker to make a certain choice in terms of an evaluation factor or to limit the evaluation factor to the values determined by itself. This function is performed by using preference functions. According to this;

a. If there is no preference for the decision-maker in terms of the relevant evaluation factor, the choice function to be selected for that evaluation factor shall be the First Type (ordinary) preference function.
b. If the decision maker wants to use the decision points with a value that is above a value determined by him in terms of the relevant evaluation factor, the preference function to be selected should be the Second Type (U type) preference function.
c. If the decision maker wants to use decision points with an above average value in terms of an evaluation factor, but does not want to neglect the values below this value, the choice function to be selected should be the Third Type (V type) preference function.
d. If the decision maker's preference for an evaluation factor is to be determined by a certain value range, the choice function to be selected must be the Fourth Type (level) preference function.
e. If the decision-maker wishes to use his / her preference for decision points with an above-average value in terms of an evaluation factor, the choice function to be selected must be the Fifth Type (linear) preference function.
f. If the deviation from the average of the relevant evaluation factor values is to be decisive in the decision maker's choice, the preference function to be selected should be the Sixth Type (Gaussian) preference function.

In the third step, by taking into consideration the determined preference functions, comparisons of decision points for each evaluation factor are made and common preference functions are determined. If A and B represent two decision points, Equation 4.24 is used for the common preference function.

$$P(A,B) = \begin{cases} 0, & f(A) \leq f(B) \\ p[f(A) - f(B)], & f(A) > f(B) \end{cases} \tag{4.24}$$

When comparing decision points, attention should be paid to whether the evaluation factor is maximized or minimized. In the application, the values entered in the software and the selected parameters are shown in the following Figure. Selected preference functions are defined as the linear preference function (Type 5) for all criteria. Because the decision maker wants to use his / her preference for decision points that have an above average value in terms of evaluation factors shown in Table 4.7.

Preferences						
Min/Max	min	max	max	max	min	min
Weight	8,60	32,40	15,20	8,10	4,60	31,10
Preference Fn.	Linear	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	1,00	100,00	50,00	10,00	50,00	0,0015
- P: Preference	40,00	40000,00	15000,00	100,00	800,00	0,0350
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a
Statistics						
Minimum	38,30	2871,00	8890,00	88,00	829,00	0,0289
Maximum	82,10	6570,00	26730,00	180,00	975,00	0,0749
Average	56,90	4820,80	16935,80	125,00	880,50	0,0528
Standard Dev.	15,74	1267,58	7093,74	30,15	42,88	0,0155

Figure 4.7 Visual Promethee parameters

In the fourth step, preference indexes for decision points compared using Common preference functions are determined using equation 28. The k value in this formula represents the number of evaluation factors. In Figure 4.8 red line shows the decision axis (π).

$$\pi(a,b) = \sum_{j=1}^{k} w_j P_j(a,b) \qquad (4.25)$$

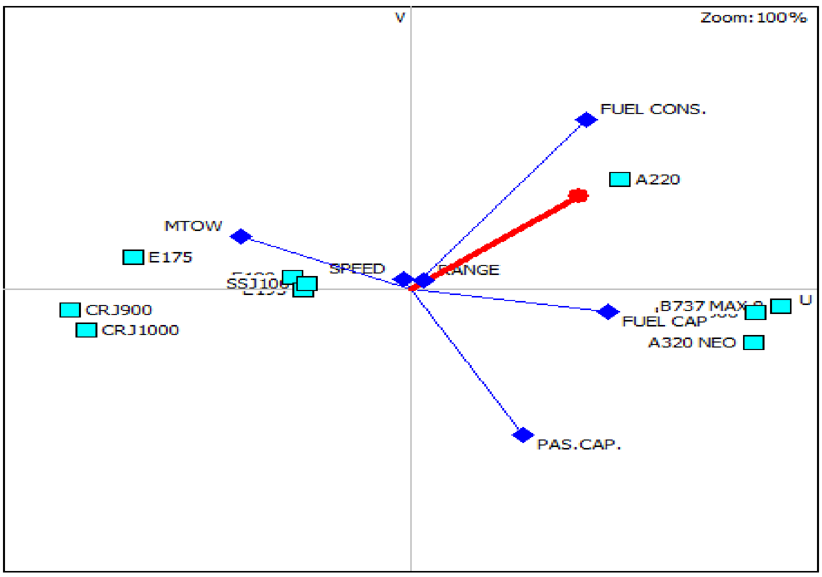


Figure 4.8 GAIA visual analysis

In step 5, the positive (Φ +) and negative (Φ-) superiority values for the decision points are determined using Equation 4.26 and Equation 4.27 respectively.

$$\phi^{+}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x) \tag{4.26}$$

$$\phi^{-}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a) \tag{4.27}$$

Here, in both formulas, x represents other decision points other than A. Therefore, the superiority values for n decision points in both formulas will be the sum of (n-1) values shown in Figure 4.9.

	MTOW	RANGE	FUEL CAP	PAS.CAP.	SPEED	FUEL CONS.
A220	-0,1681	0,0394	0,3608	-0,0765	0,0241	0,6740
A320 NEO	-0,4587	0,0395	0,6646	0,5679	0,0209	0,3987
B737-800	-0,6077	0,0227	0,6284	0,3605	-0,0421	0,4444
B737 MAX 8	-0,6678	0,0462	0,6250	0,3802	-0,0764	0,5114
CRJ900	0,4923	-0,0518	-0,5428	-0,3358	0,0117	-0,6375
CRJ1000	0,4803	-0,0472	-0,5428	-0,2049	0,0117	-0,6375
E175	0,4510	-0,0194	-0,5208	-0,3556	0,0117	-0,3244
E190	0,1439	-0,0078	-0,2939	-0,1235	0,0117	-0,1204
E195	0,1325	-0,0148	-0,2939	-0,0420	0,0117	-0,1204
SSJ100	0,2023	-0,0069	-0,0844	-0,1704	0,0150	-0,1884

Figure 4.9 Uniform criteria preference flows

In step 6, PROMETHEE 1, the partial order is determined. In this stage in which negative and positive superiority values of decision points are compared, three possible situations are the superiority of one decision point over another, the indifference of the decision points and the inability to compare the decision points with each other. In order to be superior to decision point A and decision point B, any of the following conditions must be met. P^I, I^I, R^I are preference, indifference and incomparability variables respectively.

$$aP^I b \text{ iff } \begin{cases} \phi^+(a) > \phi^+(b) & \text{and} \quad \phi^-(a) < \phi^-(b) \quad \text{or} \\ \phi^+(a) = \phi^+(b) & \text{and} \quad \phi^-(a) < \phi^-(b) \quad \text{or} \\ \phi^+(a) > \phi^+(b) & \text{and} \quad \phi^-(a) = \phi^-(b) \end{cases} \tag{4.28}$$

$$aI^I b \text{ iff } \quad \phi^+(a) = \phi^+(b) \quad \text{and} \quad \phi^-(a) = \phi^-(b) \tag{4.29}$$

$$aR^I b \text{ iff } \begin{cases} \phi^+(a) > \phi^+(b) & \text{and} \quad \phi^-(a) > \phi^-(b) \quad \text{or} \\ \phi^+(a) < \phi^+(b) & \text{and} \quad \phi^-(a) > \phi^-(b) \end{cases} \tag{4.30}$$

In the final stage, the exact order of decision points is determined by PROMETHEE 2. For the exact order of decision points, the exact priority values are calculated for each decision point using the formula in Equation 4.31, and these values are sorted from top to bottom and presented on Figure 4.10.

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{4.31}$$

	Phi+	Phi-	Phi
A220	0,3087	0,0510	0,2577
A320 NEO	0,3021	0,0568	0,2453
B737-800	0,2838	0,0677	0,2161
B737 MAX 8	0,3067	0,0678	0,2389
CRJ900	0,0429	0,3247	-0,2819
CRJ1000	0,0429	0,3137	-0,2708
E175	0,0632	0,2390	-0,1758
E190	0,0827	0,1644	-0,0817
E195	0,0849	0,1633	-0,0784
SSJ100	0,0919	0,1613	-0,0694

Figure 4.10 Multi-criteria preference flows

According to this formula for two decision points such as a and b;

• If Φ (A)> Φ (B), alternative A is superior.

• If Φ (A) = Φ (B), there is no difference between alternatives a and b.

Finally, the sequence is determined and expressed by the network diagram. Network diagram is generated according to the rank Table in Figure 4.11.

Rank	action		Phi	Phi+	Phi-
1	A220		0,2577	0,3087	0,0510
2	A320 NEO		0,2453	0,3021	0,0568
3	B737 MAX 8		0,2389	0,3067	0,0678
4	B737-800		0,2161	0,2838	0,0677
5	SSJ100		-0,0694	0,0919	0,1613
6	E195		-0,0784	0,0849	0,1633
7	E190		-0,0817	0,0827	0,1644
8	E175		-0,1758	0,0632	0,2390
9	CRJ1000		-0,2708	0,0429	0,3137
10	CRJ900		-0,2819	0,0429	0,3247

Figure 4.11 Final rank evaluation

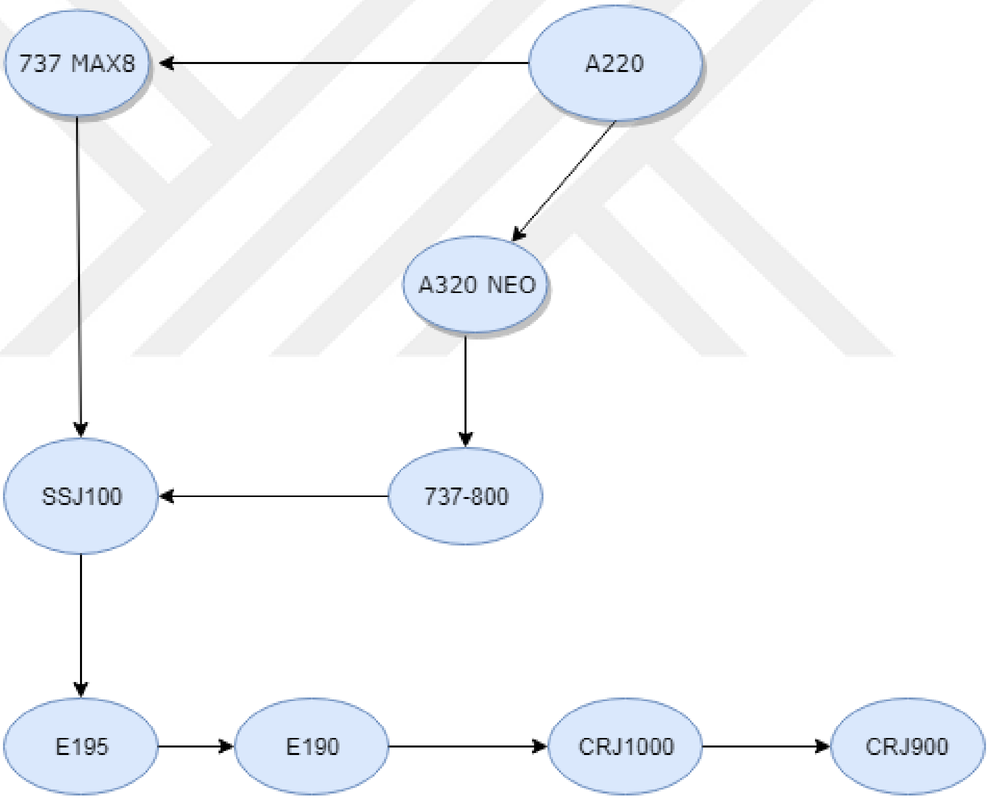


Figure 4.12 PROMETHEE network diagram

In Figure 4.12, the results obtained according to the latest analysis are presented. Airbus A220 is the type of aircraft that should be selected to form a domestic airline fleet according to PROMETHEE method.

CHAPTER 5

FLIGHT NETWORK DESIGN PROBLEM

The decision-making process of an airline consists of flight network and fleet planning, aircraft and crew scheduling. Aircraft scheduling; fleet assignment and aircraft routing; crew scheduling includes crew matching and crew scheduling [95]. In this process, the most important problems that require the company to make strategic decisions are flight network and fleet planning problems. Flight network planning includes the selection of the starting and arriving points where the transportation service will be carried out and planning the route of the aircraft between these points [96].

The liberalization experienced in the USA after the 80's had a global impact and since the mid-1980s the world airline industry has witnessed significant structural, institutional and legal changes. Many countries have gone to liberalize their domestic routes, and bilateral agreements have been signed between them. Open skies projects have been implemented in Europe and North America. Many airlines have been affected by liberalization and liberalization processes. Increasing competition and economic stagnation in this process caused great losses and losses in the international airline industry. Carriers had to go through restructuring in order to increase productivity and reduce costs [97].

The most important change in this process took place in the airline flight network structure and the airline companies developed the hub and spoke network structure and arranged the flight routes according to this structure. This has also affected other airline services and operations. Similarly, the fast-moving cargo companies developed the network of collect-distributions. The development of the add-and-distribute network structure in aviation has been one of the most important innovations after liberalization. Although the ball-distributor network structure has been brought to the agenda with successful applications in airline passenger and

Cargo transportation, it has been successfully applied in road transport, communication networks and logistics systems [98].

5.1 Comparison of Point-to-Point and Hub And Spoke Networks

Point to point and hub and spoke systems can be compared in many areas. These comparisons mainly consist of supply, demand and current ecosystem characteristics. In general, demand is highly dynamic and varies by day, week, and season, making it difficult for an airline to model demand and comply with its current capacity. Passenger demand of various cities is highly related, but network carrier companies can compensate for the decrease in their demand with the increase in demand from another company [99]. A centrally located facility in the aggregate network serves as the main distribution base (Hub). Flows from other facilities come to the main distribution base and are grouped. All flows (Spokes) are separated from this center to be sent either to other main distribution bases or directly to their destination. This centralization and expansion of the operational network brings the advantage of using economies of scale [98]. In addition, the flight network in the form of a distributor for airline companies increases the profit of airline companies and provides significant savings in costs [100]. In addition, firms in different sectors benefit from the reduction of costs if they are close to Hub within the air transportation network [101].

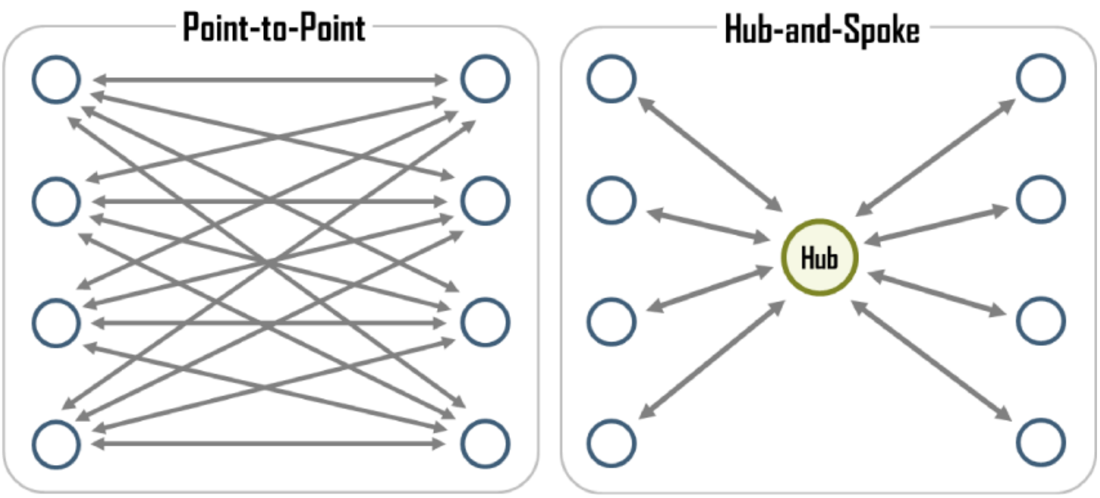


Figure 5.1 Point to point and hub and spoke architecture

As can be seen from the Figure 5.1, there are significant differences between the two systems. These differences also significantly change the flight and inner characteristics and service structure. Correct structuring of the service type and future expectations is decisive for the future position of this sector. Therefore, a general framework should be established by making a decision between these two systems at the beginning stage. Today, many airlines use hub and spoke systems. However, there are also those who use the point-to-point flight system. When looking at low-cost airlines, it is often seen that the hub and spoke system is dominant. One of the main reasons for this situation is that airlines can reduce their costs as a result of agreements and code sharing with each other and maximize total aircraft utilization.

On the other hand, the hub and spoke system has many advantages that offer flexibility. It supports high frequency flight on many routes daily. Fleet type is not dependent on a single model, seat capacity and demand is variable. It provides an environment that can be optimized as it is served in a wide geography. Use of hubs increases the cost per seat, but increases the availability of aircraft and increases profits. Basically, it can be said that the increase in the number of aircraft and flights serving on the same route will increase the supply and cause a significant decrease in prices. In this case, it is possible to say that some of the negative effects of the hub and spoke system have been neutralized. In view of all these factors, it is possible to define the flight network design problem as a hub location problem.

5.2 Hub Location Problem

The hub location problem has become an important research area of settlement theory for the last 20 years. The use of hub and spoke network structures in modern transport and telecommunications systems plays a major role in this. A centrally located plant in the hub and spoke network serves as a collection and distribution point. This center, which is used as a collection and distribution point, is called the “hub”. In hub and spoke network systems, flows between all start-arrival points are collected in hubs to benefit from economies of scale, not through direct connection lines, and are sent to the destination via hubs. Thus, with fewer connection lines, it is possible to access more points at lower costs. Hub settlement problems are seen in many sectors. It is mainly used in air transportation, postal and cargo distribution services, emergency services sector and telecommunication fields [102].

5.3 Description And Classification of Hub Location Problem

Hub location problem is in general the settlement-assignment problem, which involves locating hubs and assigning spokes to Hubs. Hub location problem involves two sub-problems: 1. Problem is choosing a location for the hub, and the second problem is the assignment of the spoke points to the designated hubs [103]. Some researchers have addressed only the assignment aspect of the problem. Since the best assignments will be influenced by hub location selections and the best hub location selections will be affected by assignment decisions, location and assignment problems should be handled together in hub network structure design [104].

In the hub layout problem, there are two different assignment structures which are single and multiple hub assignment. In single-assignment structures, the incoming and outgoing traffic of each node is sent over a single hub. This means that a node is assigned to a hub. In multi-assignment structures, each node sends or receives incoming and outgoing streams across multiple hubs. Figure 5.2 shows a single and multi-assignment hub allocation schematically.

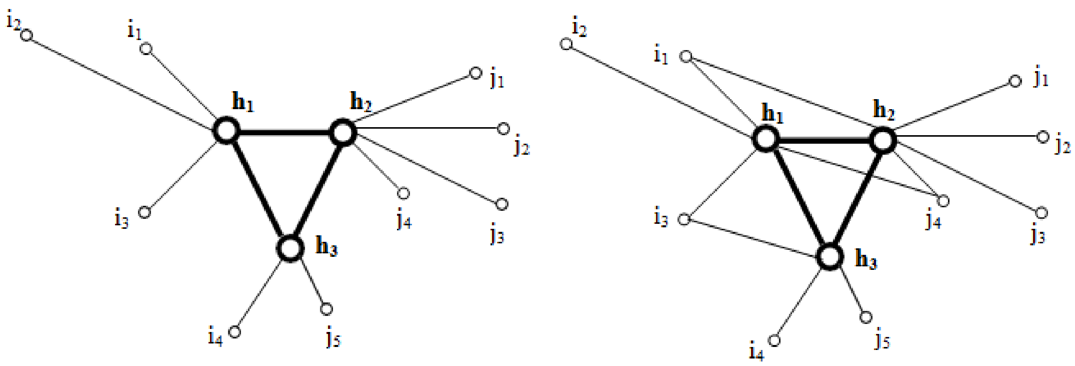


Figure 5.2 Single and multiple assignment hub location

Campbell grouped the hub location problems in four different ways, similar to the facility problems: “p-hub median”, “p-center hub”, “Hub coverage” and "uncapacitated hub location” problem [105]. These problems are briefly explained as follows;

- The p-Hub median problem is the problem of determining the locations of a fixed number of main distribution bases p and minimizing the total transport cost and assigning nodes to these points for routing traffic between the origin and destination points.
- The p-center Hub problem is similar to the p-hub layout problem. The aim is to place and assign Hubs to minimize the maximum travel cost of the main distribution base. The cost of travel or travel cost between destination and destination for each connection line can be used as the travel cost.
- Hub coverage problem is the problem of deploying main distribution bases to ensure that the cost of travel is equal to or less than a certain value and minimizes the number of hubs to cover all nodes.
- Uncapacitated hub location problem is the problem of determining the number, location of the main distribution bases and routing the traffic between the start and destination points to the nodes to minimize the total cost.

Hub location problems are defined for discrete and continuous spaces. In discrete space, the location of demand points, ie start-arrival points, is clear. In continuous space, the demand points are defined at any point in the coordinate plane. Discrete Hub placement problems were taken into consideration in the study and it was used as “Hub location problem" shortly. Hub location problems are defined for networks with n origin and destination points and potential hubs. Basic parameters of the problem; the flow data for each start-arrival pair, the unit transport cost (time, distance, monetary cost) and the cost reduction coefficient used to benefit from economies of scale in transports between two hubs [106]. The hub layout problem was first proposed by O’Kelly [107]. In this study, O’Kelly [107] developed a model for planar allocation problems.

O’Kelly developed the first model of the problem. The problem is a single-assignment p-hub median problem. The model is a binary model with a square objective function. The aim is to minimize the total cost of transport [108]. The squared integer model is accepted as the basis of Hub location problems. In O'Kelly's model, N is the set of nodes, i is the starting point of the flow, j is the arrival point of the flow, k is the potential hub point, p is the number of hubs to be opened, w_{ij} is the amount of flow from i to j, and C_{ij} is the unit transport cost and $\alpha \in$ (0 or 1) cost reduction coefficient. The x_{ik} node is a binary variable that is set to 1 if the node k is assigned to the hub, and otherwise 0 (zero). $X_{kk} = 1$ means that node k is a hub, and $X_{kk} = 0$ means that node k is not a hub. Model developed by O'Kelly is shown below.

$$Min \sum_{i,j} W_{ij} \left[\sum_{k} C_{ik} X_{ik} + \sum_{k} \sum_{m} a. C_{km} X_{ik} X_{jm} + \sum_{m} C_{jm} X_{jm} \right] \quad (5.1)$$

$subject\ to$;

$$\sum_k X_{ik} = 1 \quad \forall i \quad (5.2)$$

$$\sum_k X_{kk} = p \quad (5.3)$$

$$X_{ik} \leq X_{kk} \ \forall i.k \in N \quad (5.4)$$

$$X_{ik} \in \{0,1\} \ \forall i.k \in N \quad (5.5)$$

Constraints (5.2) and (5.5) explain the assignment to only one hub of each node. The constraint (5.4) allows assignments to be made only to the main distribution bases. The number of hubs is limited to (5.3). Objective function (5.1) minimizes the total transportation cost. In addition, heuristic algorithm was developed according to the closest facility (hub) assignment approach [108]. It is seen that CAB (Civil Aeronautics Board) and AP (Australia Post) data are mostly used to evaluate the effectiveness of the studies. CAB data were first used by O'Kelly [108]. In the next section, p-Hub median, fixed cost Hub location problems and airline transportation applications are discussed in line with the scope of the study. First, "single-assignment" and then "multi-assignment" problems are discussed.

5.4 P-Hub Median Problems Literature Overview

In p-hub median problems, assignments can be in two different structures as single or multiple assignments. In single assignment problems allow the hub location to be assigned to be in a single point, while multi-assignments allow the hub location to have multiple hubs. These problems may also include capacity constraints or establishment costs. In order to examine the development of these problems, the following Table was created. In the Table, the creators of the model are seen together with the problems and types. The studies shown in the Table 5.1 provide an overview of both single assignment problems and multiple assignment problems. It also provides insight into the heuristic algorithms that have been implemented. The Table 5.1 does not cover all the studies done in literature but summarizes the studies that can be included in the literature in chronological order. Furthermore, the first examples of the problem were also discussed and elaborated in detail with their constraints. The Table showing the chronological order is shown below.

Table 5.1 Overview p-hub allocation problems

Allocation Type	Year	Authors	Type
Single Allocation	1994	Campell	Integer programming
	1994	Aykin	A new mathematical model that allows direct connections
	1995	Aykin	A new mathematical model that allows direct connection to a predetermined number of hubs.
	1999	Ernst ve Krishnamoorthy	New mathematical model, two heuristic and branch and bound algorithm
	2005	Labbe et al.	Branch and Bound Algorithm
	2008	Costa et al	multi objective mathematical model minimizing total cost and time
	2008	Randall	Ant Colony Optimization
	2009	Contreras et al.	Lagrange Relaxation
	2009	Randall et al.	Metaheuristics
	2010	Correia et al.	Mixed integer programming
	2010	Correia et al.	ınteger Programming
	2010	Lin ve Lee	Lagrange Relaxation
	2011	Kratica et al.	Mixed integer programming
	2012	Camargo and Miranda	Generalized Benders decomposition algorithm
	2012	Taghipourian et al.	Fuzzy mixed integer programming
Allocation Type	**Year**	**Authors**	**Type**
	1994	Campell	Integer Programming

Multiple Allocation	2000	Ebery et al.	New mathematical model, two heuristic and branch and bound algorithm
	2003	Sasaki ve Fukushima	Branch and boundary algorithm for 1-stop hub allocation problem mathematical model
	2004	Boland et al.	Pretreatment procedure and constraint tightening
	2005	Marin	A new mathematical model and an heuristic algorithm based on the branch and bound algorithm in which the upper and lower limits are determined by linear programming loosening.
	2007	Rodriguez vd.	Simulated anneaneling
	2008	Rodriguez-Martin and Salazar-Gonzalez	Mixed integer programming (Branch and Cut based)
	2011	Gelareh and Pisinger	Mixed Integer Programming
	2013	Sender and Clausen	New heuristics and applications in Germany

5.5 Hub Allocation Problem Air Transportation Applications Literature Review

An important application area of hub and spoke network structures is passenger / cargo and fast package transportation by airlines. Since air passenger transport is carried by airlines, in this part of the study, the studies that have been carried out in the field of airline passenger transport as well as fast package transport and cargo transport are examined and given below. Demand or flow terms used in hub allocation problems refer, transport sector applications between a city pair aircraft, trains, trucks and so on. The number of passengers carried by means of transport or the amount of freight. Nodes refer to facilities such as airports and terminals.

Flynn and Ratick [109] conducted a study of the Essential Air Services program. In this program, air transport service is offered to small groups in the network of hub and spoke. Stop points are small cities where 1 or more stops are made before arriving at hubs. In airline transportation system, an model encompassing the objectives of minimizing airline costs and achieving maximum access by loosening the acceptance of flows through hubs [109].

Kuby and Gray [110] developed the work of Flynn and Ratick [109], taking into account feeder and pause points. In the basic hub and spoke network, the nodes are assigned directly to the hubs and the loads originating from the starting point are sent to a hub. In this study, unlike other studies, small cities are used as stopping points and the demands between these cities are carried with feeders. Feeders pick up loads from small cities and transfer them to large planes. Loads are transported to hubs by large aircraft. In this system, Kuby and Gray [110] discussed the relationship between load factor, economies of scale, time constraints and distance.

They introduced a mixed-integer model that minimizes the total network cost for Federal Express, a package transport company in West America. The model uses a specific hub. Compared to the original hub and spoke network, if the network uses standstill and feeders; showed that network costs decreased, load coefficient increased, less distance traveled and less airplanes required [110].

Fast express companies such as Federal Express use small or regional hubs as well as large hubs. Hall [111] modeled this type of hub and spoke network structure. Hall [111] examined the effect of time constraints on network design in fast packet transport. Hall [111] proposed the use of a large hub to send streams between regional and small hubs. The important point in network designs with large and small hubs is that there is a connection between hubs and the time constraint limits such connections [111].

Daskin and Panayotopoulos [112], in an existing hub and spoke network structure to maximize profit to assign a model to the route proposed. The study was developed heuristics based on Lagrange relaxation. Herusitic determines the upper limit of the objective function. In the model, the starting point of the route is a hub point and the routes are modeled to return to the hub point after the planes cross 1 or more cities [112].

Dobson and Lederer [113] expanded the work of Daskin and Panayotopoulos [112] and added the customer's preference. At an existing hub and a network of airlines, a model was introduced that sets the flight plan and sets route prices to maximize profit. Customer demand is a function of service quality and prices. Service quality is related to flight quality and flight length. An intuitive study has also been shown [113].

In the studies discussed above, hub locations within the hub and spoke network structure are evident and new characteristics are added to these structures. However, it is known that assignments are affected by hub location choices and hub location choices are affected by assignments. Considering this, researchers have developed models in which the number and location of hubs are determined together with the solution. In addition, new models have been developed by the use of direct connections between non-hub nodes, fixed costs for establishing hubs, capacity constraints to reduce congestion at hub points, constraints that prevent connection lines from opening under a certain use, and improved cost functions in the hubs between hubs.

In a basic hub allocation problem, the number of hubs is determined by the user. The number of hubs can be determined by solution, given the cost of opening hub points. The number of hubs to open depends directly on the cost of opening. As this cost increases, the number of hubs in the network decreases. Aykin [61] developed the first model with limited capacity for air transport. In the work of Aykın [61], the capacity constraint is not linear. The branch and boundary algorithm was used in the study and developed an heuristic based on clustering method [61].

Another alternative to the capacity constraint is to limit the amount of flow sent between hub locations. Such a capacity limitation limits the transport of large quantities and supports the opening of a 2nd hub on the same route. In multi-assignment models, limiting the amount of flow in the connecting lines leads to very little flow in some lines. Marianov and Serra [114] dealt with the problem in a similar way and developed a hub and spoke network structure model considering the congestion problem in airports used as hubs. The number of aircraft waiting for landing is limited by a constraint and a model has been developed according to the tail theory. The aim of the study is to determine the number of runways required for each hub.

O'Kelly [115] discusses the use of large and small hubs in the hub and spoke network, where hub locations are not clear for fast packet transport. The cost of transport is a function of the amount of flow sent through the lines. The basic hub location model uses the cost reduction coefficient for transports between hubs and is determined by the user regardless of the flow rate.

O'Kelly and Bryan [116] developed a model in which transport costs depend on the amount of flow. The authors found that in the case of basic hub location and assignment problems, if inter-hub transport costs are handled independently of the flow rate, not only the total cost calculation, but also the best hub location and assignment would be wrong. Therefore, he developed a model by using segmented linear function to reflect the economies of scale between hubs. However, it is stated that this model is more suitable for cargo transportation by air because it maximizes the load factor regardless of route [116]. O'Kelly and Bryan [116] stated that their model proposals should be modified for studies on passenger transport and that the balance between minimizing the effort of the passenger and minimizing total cost should be established.

Aykin [98] examined 3 different hub and spoke network structures using direct connections between airline and nodes for passenger transport, using 1-hub and 2-hub. Aykin [98] used the cost reduction coefficient. The study also revealed an intuitive approach to the solution of models. When the results of the solution were compared, it concluded that the total network cost of structures that allow direct routes between non-hub nodes is always less than or equal to the cost of a single hub structure [98].

Jaillet, Song and Yu [117] developed the work of Aykin [98] and introduced a hub and spoke network model. In this study, it is assumed that hub and spoke network structure is not a priority. If the cost is lower than this assumption, the resulting network structure suggests the existence of hubs [117].

Sasaki et al. [118] demonstrated the problem of choosing one-stop p-median hub locations for passenger transport by airline. In the study, it is assumed that all demand points are connected to hub points but only one hub can be used in each route. The aim is to minimize the total distance covered. A definitive solution method and two heuristics have been developed for the solution [118]. Sasaki et al. [119] studied the one-stop multitasking p-hub median problem similar to previous studies. The problem is modeled similar to the p-median problem. In the study, two heuristics based on the branch and boundary and the greedy algorithm were revealed [119].

Drezner and Drezner [120] presented a one-stop p-hub location problem that aims not to minimize the total distance traveled by the passenger in air transport. A new model was developed according to the law of gravitation [120].

Another important aspect in airline passenger transport is the effects of prices and competitive environment. A limited number of studies have been conducted on the relationship between pricing and the network structure. Marianov et al. presented a model for the problem of p-hub location selection and assignment, which could be applied to airline and cargo transportation and focused on winning customers in a competitive environment [121]. In the model, flows between origin and destination points are sent over 1 or 2 hubs and nodes can be assigned to more than 1 hub [121].

5.6 Research Problem

The history of air transport is as old as the history of trade. With the increasing population and the countries becoming dependent on each other in order to maintain their assets, the transportation sector, which is a sub-discipline of service marketing, has become more and more important. Air transportation, which is a part of the transportation sector, increases its share in the sector in parallel with this development. Especially in overseas and long distance transportation, the potential of air transportation is continuously increasing [122]. As a result of the globalization of the world economy, customers' faster and more reliable journey expectations, trends in air cargo transportation with short shelf life, increased competition in freight and fast transportation and led to the development of air transport.

The most important factors that are expected to affect the Turkish civil air transport sector in the future are; population growth rate and population structure, the amount of national income per capita, developments in the tourism sector, reflections of the liberalization movements in Europe. In addition, to help the revival of the EU candidacy process of Turkey's economy, the business connections between Europe and Turkey increased and thus are expected to increase in the passenger traffic and cargo traffic, especially the business purpose it. In the future the Customs Union and

Turkey which is a member of the European Union's history, which is considered the future of their cultural and ethnic ties to a door will be opened to the status of the Turkish Republic. In recent years, the energy agreements with these countries on both of these countries as well as Turkey's economic and geopolitical position are expected to have positive effects.

Increasing demand for air transport in the world will lead to an increase in national and international air traffic. Traffic increase volume; population density, industrial activities and the reduction of prices will accelerate further. As a result, it is inevitable to create new routes for airline companies and to restructure their network structures at this stage. Establishing the right network structure of airlines is one of the most important factors that affect the company's stay and growth in the sector. It is very important to determine the main distribution bases of the airlines serving with hub and spoke network structure. In this way, it will be possible to provide time and cost benefits for the customer and airline business. In this study, taking into account the specific characteristics of air transport, making search for solutions to hub allocation problem for a new domestic airline to minimize total cost of travelling.

5.7 Purpose of Study

In this study, it is aimed to give different dimensions to Hub allocation problems for air transportation. In the first part of the study, constraints were developed based on the performance characteristics of the aircraft and the characteristics of the transportation sector. In the other part of the study, a model was used to make the hub location selection in order to minimize the total cost.

5.8 Importance of Study

Until now, it has been found that the unique characteristics of air transport have not been evaluated for passenger transport with the aspect considered in Turkey. In this direction, taking into account the specific characteristics of airline passenger transport, the main distribution base allocation problems are aimed to be more realistic and to be usable by all airlines. In this way, it is aimed to contribute to the healthier and planned development of airline passenger transport. In addition, Turkey's flag carrier airline of the Turkish airline, to become a higher-level service airline in the world has created a gap in the domestic passenger transport. This situation led to an increase in ticket prices in domestic flights and caused a slowdown in the acceleration of airline passenger transport. However, Turkish airlines, which we can see as the mirror of Turkish aviation, are still trying to maintain the low cost trend and keep this market alive. As can be seen from the Figure 5.3 below, Turkish airlines still maintain the LCC trend.

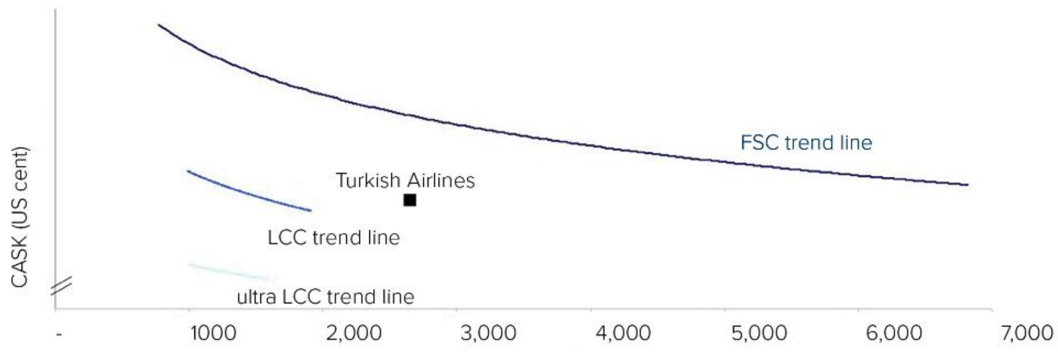


Figure 5.3 Trend line of Turkish Airlines [123]

5.9 Research Method

The p-hub median problem developed by Ernst and Krishnamoorthy [124] mentioned in the previous section and Ebery et al. [125] 's fixed cost hub allocation problem models have been rearranged considering the sectoral characteristics of air transport, and the extent to which the restrictions mentioned below and which are specific to direct air transport affect the choice of hub. In addition, taking into account the airline operating and airport infrastructure costs, the impact of different aircraft types on hub placement problems has been demonstrated.

In the calculations, passenger traffic data between airports were obtained from Turkish Statistical Institute. At the same time, the data obtained from the studies on average flight costs and the data obtained in the calculation of unit transportation costs according to aircraft types were used.

The models were programmed using licensed GAMS software and p-hub median and fixed cost hub layout problem models were solved with CPLEX solver. In the solution of the models referenced in the study, bird flight distances, flow quantities, cost reduction coefficients were used as the main determinant parameters.

5.10 Constraints and Parameters Used in Model

The parameters specific to the study are explained below, except for the common parameters that are not considered in other studies. Infrastructure costs related to the airport which may affect the hub allocation problem in air transportation are also explained.

5.10.1 Runway Infrastructure Cost

The ability of an aircraft to take off and landing from any runway; depends on the performance characteristics of the aircraft, weight, meteorological conditions and runway characteristics. For example, an airplane may take off from a runway at no load and at low air temperature, while the same airplane may not take off from the same runway at high air temperature when the same aircraft is full loaded. This situation necessitates the assessment of the suitability of the runways of the airports which will become the main distribution base according to the aircraft to be used. In the study, the suitability and adequacy of the runways were examined for two different types of aircraft (A320 NEO - A220) if airports were designated as hubs. The necessary investment costs are calculated for suitable and inadequate airports.

5.10.2 Unit Transportation Costs by Type Of Aircraft

In studies conducted to date on the hub settlement problem applied to air transport, it has been found that unit transportation costs are theoretically involved but not used due to lack of data in applications. Unlike other fields (telecommunication, postal distribution, etc.), it is determined that unit transportation costs need to be determined and used in the model in order to reach the correct results, since the cost of unit transportation in aviation varies according to the type of aircraft and each route. Aircraft types and unit transportation costs for each route, which are taken as reference, were determined and used in the model.

5.10.3 Airport Facility Cost

According to the approach of establishing the main distribution base, the amount of cargo and passengers to and from the hub will be higher than other nodes. Therefore, especially hub airports, storage areas and devices used to store and control incoming and outgoing passengers and cargoes should be sufficient. In this study, airports were examined in this respect and necessary investment costs were determined for inadequate airports.

5.10.4 Range Constraint

Distance is one of the important determinants of hub location selection and assignment. Since aircraft is used as an inter-node connection line in aviation applications, the distance between node-hub and hub-hub connections should not be greater than the range of the aircraft. Therefore, the range of the aircraft should be considered in these problems. For this purpose, a range limitation was used in the study.

5.10.5 Traffic Continuity Constraint

Air transport is a sector affected by seasonal fluctuations. When the traffic data of airports are examined, it is seen that some airports are used extensively in some months and not at all in some months. Investing in airports that do not have regular traffic during the year and which are not used extensively but which are candidates for hubs may increase the cost. For this purpose, a constraint that controls the continuity of cargo traffic has been put forward in order to designate airports with continuous traffic as hubs.

5.11 Developed Model

In the first part of the study, mixed integer linear models were developed for uncapacitated multi-assignment p-hub median under traffic control constraints. Information about the developed model is given below.

5.11.1 Uncapacitated Multi Allocation P-Hub Median Problem Under Traffic Control (MApHuTC)

In this study, constraints and objective function have been developed for p-hub median and fixed cost hub allocation problems. Firstly, the developed constraints and purpose function are explained and then the models are given. The ability of an aircraft to take off and landing from any runway; depends on the performance characteristics of the aircraft, weight, meteorological conditions and runway characteristics. Unlike the areas where hub allocation problems are applied, such as telecommunications and postal distribution, the use of airplanes as connection lines in air transport and the establishment or improvement of the airports where these airplanes take off and landing require very high costs. In addition, since airports to be designated as hubs will be used extensively, the facilities should be sufficient to meet this heavy traffic. Additional investment will be required in airports with inadequate facilities. Therefore, in order to make the hub location selections and assignments realistically and accurately, it has been seen that both the costs related to the connection lines, for instance unit transportation costs and the costs that may arise for the airports should be taken into consideration. The objective function is therefore arranged as follows, taking into account the transport and airport infrastructure costs. Here, the previously defined parameter, decision variables are used exactly. The following parameters were used differently from O'Kelly's model [108].

Sets, Decision Variables and Parameters

N: Airports, T: amount of passengers,

n: Number of airports, p: Number of Hubs will be opened

i: Departure point, j:Arrival Point , k and l: Potential Hub points

$$H_k = \begin{cases} 1 \ if \ k \ is \ assigned \ as \ Hub \\ \quad Otherwise \end{cases}$$

B_{kl}^{i}= The amount of flow passing through Hubs k and l from the starting point i.

A_{lj}^{i}= The amount of flow from the starting point i and passing through the Hub l to the point j

E_{ik}= The amount of flow from the starting point i to Hub k.

I_k = Airport infrastructure cost

F_k= Airport Facility restoration cost

C_{ij} = Unit cost between i and j

d_{ij}= distance between points i and j

R=Maximum range, $PT_{(month,k)}$: passenger traffic on month k

FL_i = Total flow rate out from node i

FL_{ij} = Amount of flow from i to j

α, β, γ = cost reduction coefficients (hub-hub, hub-node, node-hub)

$$Min \sum_{i \in N} \sum \gamma c_{ik} \, d_{ik} E_{ik} + \sum_{k \in N} \sum_{l \in N} \alpha c_{kl} \, d_{kl} B_{kl}^{i} + \sum_{l \in N} \sum_{j \in N} \delta c_{ij} \, d_{ij} A_{lj}^{i} + \sum_{k} (I_k + F_k) H_k \tag{5.6}$$

Subject to;

$$\sum_{k \in N} H_k = p \tag{5.7}$$

$$\sum_{k \in N} E_{ik} = FL_i \qquad \forall i \in N \tag{5.8}$$

$$\sum_{k \in N} A_{lj}^{i} = FL_{ij} \qquad \forall i, j \in N \tag{5.9}$$

$$\sum_{I \in N} B_{kl}^{i} + \sum_{j \in N} A_{kj}^{i} - \sum_{I \in N} B_{lk}^{i} - E_{ik} = 0 \qquad \forall i, k \in N \tag{5.10}$$

$$E_{ik} \leq FL_i H_k \qquad \forall i, k \in N \tag{5.11}$$

$$A_{lj}^{i} \leq FL_{ij} H_l \qquad \forall i, j, l \in N \tag{5.12}$$

$$A_{lj}^{i}, B_{kl}^{i}, E_{ik} \geq 0 \qquad \forall i, j, k, l \in N \tag{5.13}$$

$$d_{ik} H_k \leq R \qquad \forall i, k \in N \tag{5.14}$$

$$TH_k \leq PT_{(month,k)} \qquad \forall k \in N \tag{5.15}$$

$$H_k \in \{0,1\} \qquad \forall k \; and \; integer$$

Part 1 of the objective function includes transportation costs, and part 2 includes the total infrastructure costs that may arise if the airport is designated as a hub. The objective function (5.6) minimizes the total cost. The constraint (5.7) provides that the number of hubs is limited to p. The constraints (5.8), (5.9) and (5.10) are the constraints that show the flows of each starting point. (5.11) restricts flow to a non-hub point. (5.12) restricts the distribution of flow from a non-hub to other points. (5.13) is an integer constraint. (5.13) constraint is provided to take positive value of flow amount decision variables.

Aircraft performance characteristic is the ability of the aircraft to perform the expected task under certain conditions. Performance characteristics of the aircraft differ from each other and one of these characteristics is the range of the aircraft. Distance in hub placement problems is one of the important factors in determining hub location selections and assignments. Since aircraft are used as connecting lines in aviation, the effect of the range of the aircraft to be used must also be taken into account. The aircraft's range must be greater than the distance between the hub-hub and node-hub in the network structure. Therefore, the range of the aircraft to be used in the problem has to be taken into consideration and a range constraint has been developed for this purpose. Constraint to indicate the range of the aircraft S is as written in equation (5.13).

$$d_{ik}H_k \leq R \qquad \forall i,k \in N \qquad (5.14)$$

With the constraint (5.14), taking into account the range of the aircraft, it is ensured that the distance between the two nodes is at lower distances than the range of the aircraft in determining hub location and assignments. Range of the aircraft; is determined for 2 cases when the aircraft is idle and fully loaded. Since one of the objectives of hub allocation problems is to transport high loads, especially between hubs, the aircraft may need to fly when loaded with full load between two nodes. Therefore, in the range limitation of the aircraft, range determined by the maximum take-off weight” must be taken into consideration.

When the monthly passenger traffic data of airports are examined, it is seen that some airports are used intensively in some months and less used in some months. The current traffic here may be shifted to other modes of transport due to irregular and small traffic. Instead of investing in these airports, it would be a good approach to use existing airports more effectively. In addition, some airports are used under their capacity due to their unhealthy infrastructure despite the high traffic demand.

Investing in airports that do not have regular traffic during the year and which are not used extensively but which are candidates for hubs may increase the cost. However, it would be a more appropriate approach to invest in airports that have regular traffic and over a certain amount but have insufficient infrastructure.

For this purpose, a constraint that controls the continuity of cargo traffic has been developed. Hub location decision variable previously defined was used in the same way. T is the limit for the amount of passenger traffic and PT_k is the total monthly passenger flow of the airport.

$$TH_k \leq PT_{(month,k)} \qquad \forall k \in N \tag{5.15}$$

(5.15) restricts the allocation of airports with a monthly road traffic (PT) above a certain amount as hubs. The restriction is designed to take into account flows in all months of the year and is also possible to cover certain months of the year. The constraints developed can be appropriately arranged for all types of hub layout problems. In the study, constraints were applied to the multi-assignment p-hub median problem and the results were analyzed

5.11.2 Implication of Model

In this section, firstly selected aircraft types are mentioned and brief information is given about the A320 NEO, A220 and B737 MAX-8 aircrafts referenced in the study. In the next section, the airports evaluated in the study are mentioned. The study of the suitability of airport runways according to runway requirements and calculation of runway investment costs are explained. In the same section, information about unit transportation costs is given.

5.11.3 Aircrafts Which in Service in Turkey

The list of aircraft created for use in the study is mentioned in the previous chapters. According to the results obtained at the end of the multi-criteria decision making process, candidate aircrafts were identified and these aircrafts were included in the modeling process.

Since 2013, 13 airline companies have been operating in Turkey's civil aviation sector. 3 of them only carry cargo and our flag carrier THY A.O. operates in both passenger and cargo transportation. The number of airline companies was 489 in 2015, 540 in 2016 and 517 in 2017. In this context, the total passenger-seat capacity of airlines was 90,259 in 2015, 100,365 in 2016 and 97,500 in 2017, respectively. Cargo load capacity increased to 1,866,450 kg as a result of 3 new aircraft joined the fleets. The aircraft fleets used are different variations of the B737 and A320 series of Airbus and Boeing, which are mainly used in medium-long-range flights. There are also different variations of B777 and A330 series aircraft for long haul flights.

One of the reasons why three different types of aircraft were selected in the study is that the selected aircraft types fall into different categories and therefore show significant differences in terms of runway requirements and unit transportation costs. Also making the application of models developed on air transport in Turkey and types of aircraft A320 and B737 aircraft because it is the most widely used aircraft types in Turkey were selected. Calculating costs according to these two types of aircraft and using them in models; Hub also provides the opportunity to determine the impact of aircraft type on site selection and assignment and to compare between aircraft.

5.11.4 Airports Evaluated in the Study and their Characteristics

DHMİ to determine the air cargo network in Turkey (State Airports Administration) in the year 2018 examined the statistics used in 17 airports and airline transportation in density was determined accordingly. International code abbreviations of airports were used in the study. The characteristics of these airports are taken from AIP (Aeronautical Information Publication) documents and used.

5.11.5 Determination of Airport Infrastructure Costs

Airport infrastructure costs; runway costs and passenger transit terminal costs. Firstly, it was examined whether the runways were sufficient for the use of the designated aircraft, and then the improvement costs of the runways were mentioned according to the results of this investigation.

5.11.6 Determination of Runway Requirements due to Aircraft Types

Ability of an aircraft to take off and landing from a runway is depend on; performance characteristics, weight, meteorological conditions and runway characteristics. Apart from the varying aircraft weight and meteorological conditions it also depends on the following physical characteristics of the runway.

The reference runway length, width and strength to which an aircraft can take off and landing is determined by standard atmospheric conditions and sea level conditions during aircraft design, and this information is contained in the aircraft's flight manual. Again in these books, the various weight and configurations of the aircraft, the required runway length, strength according to various altitude values and different weather conditions (temperature and wind conditions) and the runway's physical characteristics are presented in Tables or diagrams. However, flight manuals may not be sufficient to determine the appropriate runway length. The required runway length must be calculated taking these data into account.

5.11.7 Evaluation of Runway Length Adequacy

The first step in calculating the required runway length is to determine the reference runway length in accordance with the operational requirements of the aircraft. Reference runway length; is the runway length required for take-off and landing at zero altitude, zero wind and zero runway slope conditions under standard atmospheric conditions. This information can be found in the relevant documents of the aircraft or in the ICAO documents.

The reference runway length should be increased by 7% for every 300m altitude relative to the altitude of the runway. The runway length, which is increased relative to the altitude, must be increased again by 1% for every 1 ° C exceeding the challenge reference temperature. When the total increase rate according to the altitude and temperature exceeds 35%, the necessary correction is obtained with a special study. The operational characteristics of some aircraft do not correspond to the correction coefficients for altitude and temperature, and a separate study is required to determine the required runway length of such aircraft according to operational requirements and the current conditions of the region [126]. The procedures for determining the required runway length described above are given in the formulas below.

RL_{1} = Runway length required for take-off at standard atmospheric conditions at sea level (m)

A_E = Altitude of the airport (m)

T_{RA} = Airport reference temperature (°C)

T_{SA} = Temperature of airport altitude under standard atmospheric conditions (°C)

S_{RL} = Slope of Runway(%)

RL_2 = Required runway length adjusted for altitude (m)

RL_3 = Runway length adjusted for altitude and temperature (m)

RL_4 = Runway length adjusted for altitude, temperature and runway slope (m)

$$T_{SA} = -1\left[\left(\frac{6,5}{1000}A_E\right) - 15\right] \quad (5.16)$$

$$RL_2 = \left[RL_1 * 0,07\frac{A_E}{300}\right] + RL_1 \quad (5.17)$$

$$RL_3 = [RL_2(T_{RA} - T_{SA})0,01] + RL_2 \quad (5.18)$$

$$RL_4 = [RL_3 * S_{RL} * 0,01] + RL_3 \quad (5.19)$$

Runway altitude and reference temperature values of the airports discussed in the study and the required runway lengths were calculated by considering the maximum take-off weight of the aircraft. From these calculated values, the runway lengths to be added were determined by subtracting the length values of the existing runways. Runway slopes were neglected in the study. Runway lengths required to take off with maximum weight in order to determine the runway lengths of the aircraft subject to the study are obtained from the properties book presented in Table 5.2.

Table 5.2 Required runway length

Aircraft	Required runway length (MTOW)
A220	2090 m
A320 NEO	1460 m
737 MAX8	2500 m

Based on these lengths, the runway length calculations for the maximum take-off weight mentioned in section 5.11.7 were made for all aircraft. The reference temperatures and lengths of airports were obtained from publications published by AIP (Aeronautical Information Publication).

Table 5.3 Adjusted required runway length

AIRPORTS	ELEVATION (m)	REFERENCE TEMP.(°C)	CURRENT RUNWAY LENGTH (m)	REQUIRED RUNWAY LENGTH (m) A320NEO	REQUIRED RUNWAY LENGTH (m) A220	REQUIRED RUNWAY LENGTH (m) 737MAX8
IST	50	26,00	3000	2332	1629	2790
ESB	953	26,00	3750	2332	1629	2790
ADB	126	28,00	3240	2396	1674	2866
AYT	54	34,00	3400	2523	1762	3018
DLM	42156	34,00	3000	2523	1762	3018
ADA	20	34,00	2750	2544	1777	3043
TZX	43708	26,00	2640	2354	1644	2815
BJV	16589	34,00	3000	2523	1762	3018
TEQ	175	23,00	3000	2290	1600	2739
DIY	686	31,00	3549	2459	1718	2942
EZS	892	27,00	1720	2375	1659	2841
ERZ	1757	19,00	3810	2206	1541	2638
GZT	706	27,00	3000	2375	1659	2841
ASR	1795	17,00	3500	2163	1511	2588
KSY	1068.64	22,00	3000	2269	1585	2714
MLX	861.68	27,00	3350	2375	1659	2841
VAN	1669	22,00	2750	2269	1585	2714
SAW	95	25,00	3000	2332	1629	2790

Runway lengths calculated by reference temperature, elevation and runway length are shown in Table 5.3. Also it is calculated how long the runways of the airports which are considered unsuitable for take-off and landing are calculated and shown in Table 5.4.

Table 5.4 Airport runway requirements

AIRPORTS	RUNWAY LENGTH REQUIRED TO EXTEND (m)A320NEO	RUNWAY LENGTH REQUIRED TO EXTEND (m)

		737MAX8
IST	0	0,00
ESB	0	0,00
ADB	0	0,00
AYT	0	0,00
DLM	0	17,67
ADA	0	292,96
TZX	0	175,35
BJV	0	17,67
TEQ	0	0,00
DIY	0	0,00
EZS	655	1120,64
ERZ	0	0,00
GZT	0	0,00
ASR	0	0,00
KSY	0	0,00
MLX	0	0,00
VAN	0	0,00
SAW	0	0,00

As a result of the calculation, the A220 aircraft has limits that can take off and take off at all airports. However, EZS airport was not deemed suitable for landing of A320 aircraft. In the same way, the runway of DLM, ADA, TZX, BJV and EZS airports was not suitable for the use of 737 MAX. Runways of airports which are not suitable should be extended. Since runway length was chosen as the main cost criterion in the study, runway widths were not taken into consideration. More detailed study is required to determine costs. In addition, the revised cost of the facility and the revised cost of the runway were processed together.

5.11.8 Determination of Unit Transportation Costs

The unit cost is the cost of producing 1 unit of product and the unit transportation costs are calculated by dividing the total operating cost per flight to the desired ton-mile. Unit transportation cost; it differs according to airline, type of aircraft used and routes. In the study, unit transportation costs were determined separately for A220, A320NEO and 737MAX-8 aircraft according to each route. In the calculation of these costs, the data presented by MIT's airline data project were used. The data obtained are given directly as CASM (Cost available seat mile) and used proportionally for each aircraft.

Basically, costs are examined under 4 main headings. However, many airlines consider cost headings under three headings: ACMI (Aircraft, Crew, Maintenance, Insurance), fuel and other expenses. ACMI expenses per flight are aircraft, crew, maintenance and insurance expenses. Fuel cost is the monetary value of the amount of fuel consumed on that flight. Fuel consumption depends on a number of parameters, such as the configuration, speed, weight, position of the throttle, altitude, meteorological conditions and flight time in each flight phase of the aircraft [127]. However, in the study, when calculating ACMI which includes all expenses, the cost per kilometer and the distance between two points are multiplied.

5.11.9 Determination of Distances

The google maps program was used to determine the distance data. Program; by evaluating the information and data entered, flight distance and flight time are given as a result. The distances between the nodes and the flight times have been determined as close to the reality to be used in this program.

5.12 Analysis Results and Evaluations of Models

The analysis of how the best solution will be affected in case of variations in the parameters or structure of the model is called "sensitivity analysis". Sensitivity analysis can be applied in linear decision models. Since the hub placement problem models used in the study are mixed integer linear and nonlinear decision models, sensitivity analysis methods cannot be applied. Therefore, at this stage of the study, in order to observe how the results change with the change of the structure of the parameters and models in hub placement problems, different values of the parameters and newly developed constraints were applied to the models and the results were analyzed. The inter-hub cost reduction coefficient α is 0.1; node-Hub, Hub-node cost reduction coefficients are taken as χ is 0,2 and δ is 0,2. The models are solved with the CPLEX solver in the Hub allocation problem programmed using the licensed GAMS software. Multi-assignment p-hub median problem GAMS code is attached.

5.12.1 Effect of Traffic Flow

While the flow traffic values between all start-arrival points are constant (W_{ij} = cst and W_{ii} is 0); p is 2 for SAW and ADA; for p is 3, ADB, IST, ADA p is 4 and more, depending on the hierarchy of airports as hubs; shows that hub points are determined according to distances when flow traffic is ignored. Especially considering that the opening of a route in the transportation sector depends on the demand between the two cities, it is clear that ignoring flow traffic in such problems will not be the right approach. When real flow data is entered as a parameter, it is seen that hub locations change. For p is 2 for ADA and IST; p is 3 for AYT, IST, TZX; p is 4, AYT, ESB, TZX and IST airports are designated as hubs; It shows that passenger flow traffic and distances between nodes are the main determinants in locating hubs.

Table 5.5 Hub locations determined by real data

	Cost	Hub Locations	Cost Decrease(%)
P=1	698Mn	SAW	39,97
P=2	419 Mn	ADA-IST	30,55
P=3	299 Mn	AYT-IST-TZX	1,03
P=4	294 Mn	AYT-IST-TZX-ESB	0,68
P=5	292 Mn	ADA-ADB-AYT-SAW-TZX	0,34
P=6	291 Mn	ADA-ADB-AYT-ESB-IST-TZX	0,34
P=7	290 Mn	ADA-ADB-AYT-ESB-IST-SAW-TZX	0
P=8	0	INFEASIBLE	0
P=9	0	INFEASIBLE	0
P=10	0	INFEASIBLE	0
P=11	0	INFEASIBLE	0

5.12.2 Effect of Infrastructure Cost

In order to observe the effect of infrastructure costs on the solution results, the objective function of the model was changed and the impact of infrastructure costs that may arise in case an airport is a hub was reflected. Airport infrastructure costs are determined separately for all aircraft and are included in the model as such. According to the results of the analysis of the number of hubs 2, 3 and 4, the same airports were identified as hubs for all aircraft types. The common point in determining the mentioned airports as hubs is that the designated airports either do not require infrastructure costs or require very little infrastructure costs. When p = 5, it is seen that higher cost is obtained when A320 NEO and 737MAX8 aircraft are used. The reason for this is that Adana Airport, one of the airports designated as hub, has infrastructure costs. Therefore, it is clear that infrastructure costs affect the total cost. This shows that infrastructure costs should be taken into consideration in hub location problems.

Table 5.6 Effect of infrastructure cost

AIRCRAFT TYPE: A320		**AIRCRAFT TYPE: B737-8MAX**	
COST (MillionTL)	**HUB LOCATIONS**	**COST (MillionTL)**	**HUB LOCATIONS**
915	SAW	915	SAW
483	IST-MLX	483	IST-MLX
325	DLM-MLX-SAW	326	DLM-MLX-SAW
276	ASR-ERZ-DLM-SAW	277	ASR-ERZ-DLM-SAW
239	ADB-AYT-ESB-EZS-IST	239	ADB-AYT-ESB-EZS-IST
213	ADA-ADB-AYT-ESB-EZS-IST	213	ADA-ADB-AYT-ESB-EZS-IST
204	ADA-ADB-AYT-ESB-EZS-IST-EZS	205	ADA-ADB-AYT-ESB-EZS-IST-EZS
0	INFEASIBLE	0	INFEASIBLE
0	INFEASIBLE	0	INFEASIBLE
0	INFEASIBLE	0	INFEASIBLE
0	INFEASIBLE	0	INFEASIBLE

5.12.3 Effect of Range Constraint

Since the range of all aircraft is sufficient, the range constraint has not been observed to create significant differences. However, it can be said that instead of the types of aircraft used, smaller and shorter range aircraft will change the hub points to be selected. In this circumstance, range constraint is affects locations of hub points to be selected. For instance, when range is decreased from 2000 km to 700 km, hub locations are getting closer to each other.

5.12.4 Effect of Traffic Continuity Constraint

In the study, the monthly passenger traffic limit was determined as 200000 passengers. Analyzes were made for 2, 3 and 4 values of hubs and results were obtained. According to these results, it is observed that monthly passenger traffic constraint is used and when not, the same airports are designated as hubs. This is due to the fact that the airports designated as hubs have a regular and exceeding amount of passenger traffic for 12 months. In other words, the current annual and monthly passenger traffic flow data conforms to this limit. Different results will be obtained with different data. In the last analysis, all constraints, parameters and new objective function were used.

5.12.5 Effects of Number of Hubs

In order to observe the effect of hub number (p), the model was programmed and run for different p values. The results of the analysis are given in the Table. According to the analysis results; for all types of aircraft, the cost of the number of hubs from 2 to 6 is gradually decreasing, and in the case of 6 hubs it reaches its lowest value. However, this value does not show a significant decrease. Costs become stable if there are more than 6 hubs. In this case, it is possible that the ideal hub number for all species will be 3. Similarly, for all aircraft types, p is given from 2 to 7 and it is seen that the total cost for p is 7 reaches the minimum value. If p is higher than 7, the best solutions cannot be achieved.

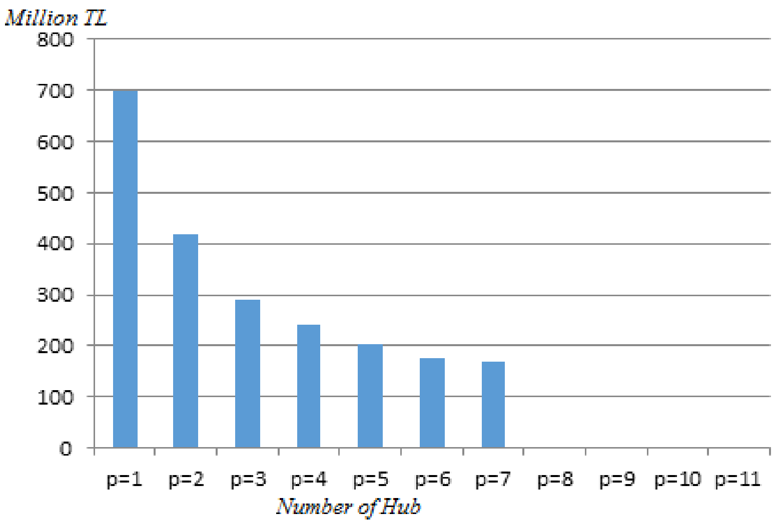


Figure 5.4 Relationship between number of hubs and total cost for A220

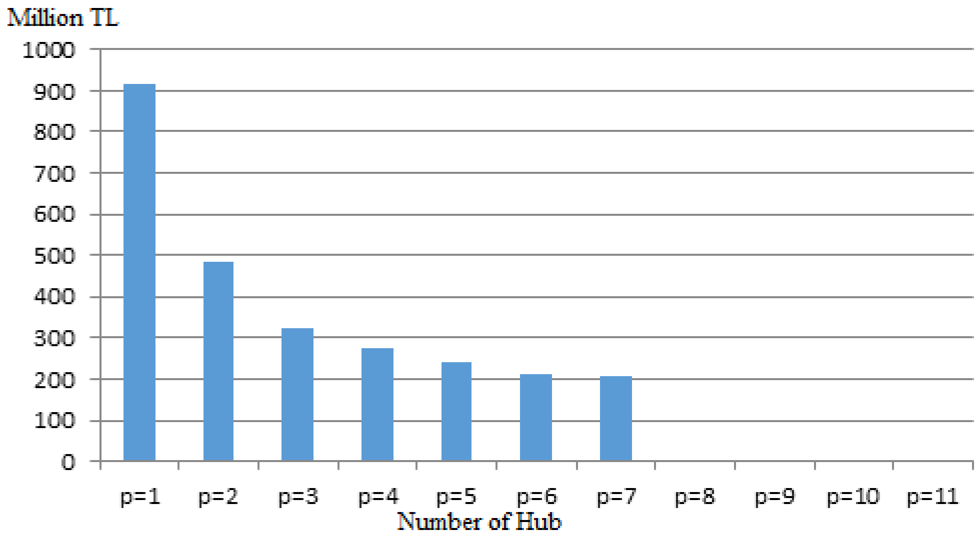


Figure 5.5 Relationship between number of hubs and total cost for A320 and 737MAX8

As the A320 and 737MAX8 aircraft show similar characteristics in terms of costs and the total cost is high, all analyzes performed at this stage have been made considering A220 aircraft. It can be said that the lowest value is the optimal number of hubs for p is 7. However, the total hub amount was chosen as 3 because the break point was p is 3 in terms of the graph of decrease in costs.

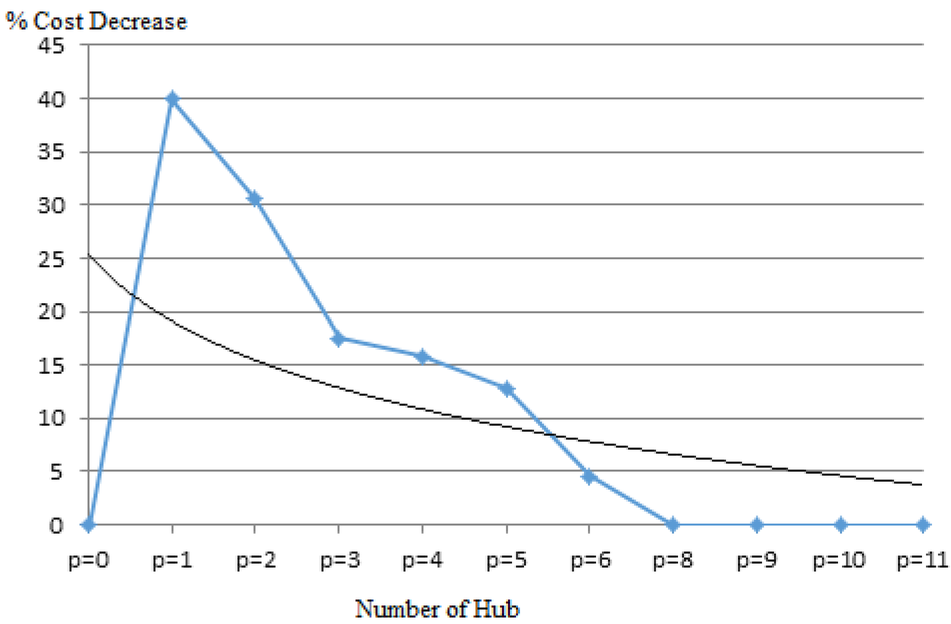


Figure 5.6 Cost saving due to costs and trend line

As seen from Figure 5.6, the decrease in costs has created a trend curve. The elbow point of the trend curve is p is 3. From this point on, the costs continue to decrease but the situation becomes stable. The experiment shown in Table 5.7 is designed to understand how all constraints interact with each other. This experiment was developed to observe how constraints were incorporated into the model and influenced the model and contributed to the results. This study was tested for all aircraft types. However, it was observed that it only led to changes in the total cost amount. The behavior of the constraints is unaffected. Thus, hub points were determined and accommodation centers of the flight network were established. Following this process, a study will be carried out on which hubs the flights and demands should be met and flight legs will be determined. The model used to determine flight legs is a basic supply-demand model. It covers meeting the demands from supply points at the minimum possible cost. For these reasons, the hub to be selected is p is 3.

Table 5.7 Behavior of model due to constraints for p=2

Hub #	Specification	Hub Location	Definition
p=2	FLij=dij= cst, I (k)=0	ASR, IST	The model selects and assigns hub locations based on geographic locations.
	FLij , dij, I (k)=0	IST, MLX	By entering flow data, hub location selection and assignments have changed.
	FLij ,dij, I (k)	IST, MLX	The infrastructure costs of airports designated as hubs are I (k) 0 (zero).
	FLij ,dij, I (k), C_{ij}	IST, MLX	Since the unit transport costs of the A220 aircraft bring extra transport costs, the total cost has increased, although the same hubs have been identified.
	FL_{ij} , d_{ij}, I (k), C_{ij}, R	IST, MLX	According to previous analysis is sufficient according to the range A220 aircraft has been no change in the geography of Turkey

		selection in the hub. However, in the experiments carried out by decreasing the range, it was seen that the cost increased.
FLij , dij, I (k), C_{ij}, PT(month,i)	IST, MLX	Passenger traffic of the airports designated by the model as hubs is continuous.
FLij , dij, I(k), C_{ij}, R, PT(month,i)	ADA, ESB	All parameters and constraints were used in this analysis. According to all parameters, different airports were identified as hubs and different costs were obtained.

5.13 Determination of Flight Legs

The flight leg is the flight that starts and finishes at an airport at a specified time defined in the flight schedule. The flight leg includes the time interval between the take-off and landing of the aircraft. When designing a flight network, flight legs are formed by considering supply and demand balance. Flight legs are essentially each unit that forms an airline's flight network. These units can be created from hubs to node points or between node points. This is directly related to the approach used. The flight legs used may be directly to the final destination to be reached or a leg used for passenger transfer.

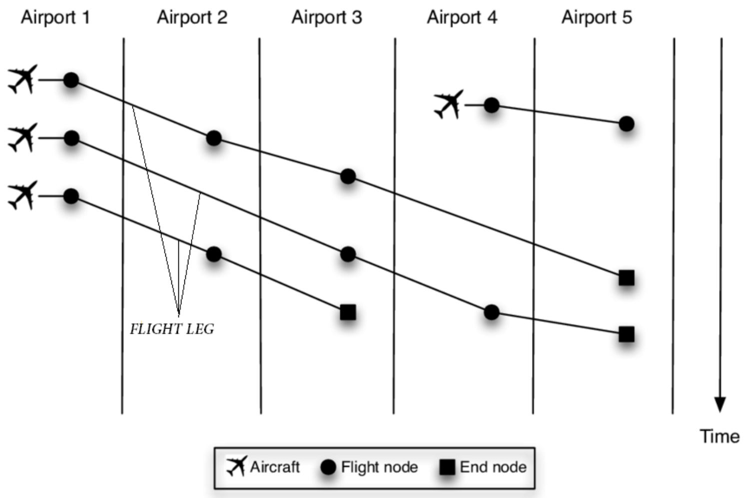


Figure 5.7 Flight legs and nodes

Transportation problem aims to bring the relation between the transportation costs and the goods to be transported between supply and demand points at an optimum point. In this sense, it is possible to use transport problems to establish the distribution network between the supply and demand points. However, such basic models do not indicate how much the flight frequencies of the established networks should be. It offers only the initial solution. Basic model can be summarized as follows [131];

$i = Hub\ Airports$
$j = Node\ airports$
$S_i = Capacity\ of\ Hub\ airports$
$D_j = Demand\ of\ node\ airports$
$c_{ij} = Unit\ transportation\ cost\ of\ one\ passenger$
$x_{ij} = Passenger\ flow\ from\ i\ to\ j$

$$Min\ Z = \sum_i \sum_j c_{ij}\, x_{ij} \qquad (5.20)$$

Subject to;

$$\sum_j x_{ij} \leq S_i \quad x_{ij} \qquad (5.21)$$

$$\sum_i x_{ij} \geq D_j \quad x_{ij} \qquad (5.22)$$

$$\forall\ i, j\ \in N$$

Where, Eq. 5.20 minimizes the total passenger transportation cost due to distance between node i to j. Eq.5.21 satisfies allowable supplied passenger and 5.22 fulfills minimum amount of passenger must be transferred.

The current model only specifies the amount of passengers that must be transported between hub destinations and final destinations, and from which hub to which final destinations. Considering these conditions, result obtained when the above model is solved with the available parameters is indicated in the Table below. Model aims to transport passengers supplied from hubs to demand points. However, this does not mean that it can never fly to hubs. Hub points are directly connected to each other.

Table 5.8 Hub-node pairs

Main Hub	Node	Main Hub	Node	Main Hub	Node
	ADA				DIY
	ASR		ADB		ERZ
AYT	BJV	IST	ESB	TZX	EZS
	DLM		TEQ		KSY
	GZT				MLX
	SAW				VAN

Demand points used in the model are the same data used to determine hub location. However, the points are constructed to meet the demand of only about 1% for the demands in Turkey. There are no restrictions on the number of passengers that can be sent from hubs.

This approach aims to minimize the costs resulting from the distance between hubs and nodal points, thus providing the total number of passengers at the shortest possible distance. So the legs of the flight were outlined. However, no realities have been presented as to the frequencies of these flight legs and whether connections between nodes are required. The primary reason why this reality cannot be presented is that accessible data are not sufficient to investigate this reality.

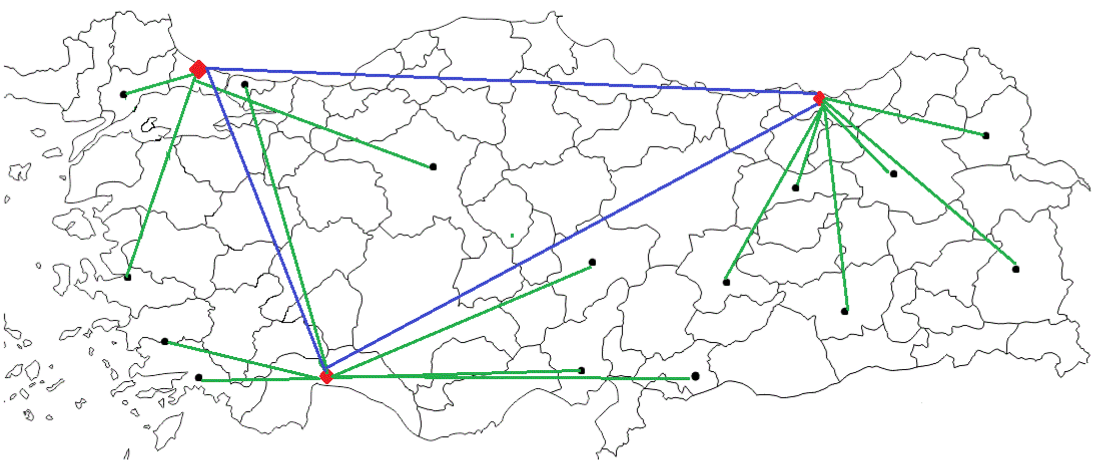


Figure 5.8 Outline of the constructed flight network

As shown in Figure 5.8, flight network and hub usage is provided through 3 main hubs. There is a direct connection between hubs, but no direct connection between nodes connected to hubs. However, it is common for low-volume air carriers to use interconnected flights between nodes. The main reason for this is to increase the demand from that point to the main hubs and increase the recognition of the company. As it is mentioned in this thesis, this volume is not sufficient for most airports when it is desired to include only 1 to 10 percent of the flights as the basic approach. Therefore, when creating a flight schedule, node connections were initially allowed with limited conditions and are described in section 5.14 as an extension to this section.

5.14 Determination of the Time Dependent Flight Network Design Under Fleet Variations (TDFNuFA)

The creation of the flight schedule is not based on the exact flight schedule, but on the principle of routing the fleet to transport the requested passengers. This is because the number of aircraft needed in the selected fleet and the direct flights on which routes are required is a problem in itself. Therefore, the fleet routing problem was studied as an extension of the hub location selection problem and the routes from the main hub points to the node points were determined. Initially, direct connections between nodes were limited in the first place, as the daily requests received were not sufficient. In the extension model written to the main model, multi-objective mixed integer model was used. Test problems were created and compared when constructing the model. Test problems are basically; minimum cost is based on minimum time. In addition, models were run separately for homogeneous and heterogeneous fleet and their differences were examined.

For the homogeneous fleet routing model, the minimum cost A220 aircraft obtained from the aircraft selection procedures performed in the previous sections was used. For heterogeneous fleet routing problem A220, B737MAX8 and A220, A320NEO pairs were used respectively. In addition, time windows were used in the model and the maximum working time was determined as 8 hours (480 minutes). This will provide information on cabin crew requirements and provide insight into the basic workforce. Vehicle routing problem used to create flight schedule is explained below. The earliest and latest time values in the time windows assigned to the airports have been created considering the transportation possibilities to the airport. In addition, airport service periods are used in proportion to the size of the airport. Flight times between airports were obtained through Google Maps. Improved version of O'Kelly and Bryan's flight network problem described as uncapacitated time-dependent flight network design problem under fleet variations [64].

$\boldsymbol{Notations}$:

$i, j:\ Origin\ and\ Destination\ Airports\ (i = 1\ and\ j = 1\ hub\ points\ )$

$K\ : Aircrafts$

$\boldsymbol{Parameters}$

k: $number\ of\ aircrafts$

N: $number\ of\ airports$

$P_{\ k}$: $capacity\ of\ aircraft\ k$

$D_{ij}\ :\ distance\ between\ airport\ i\ to\ j$

Y_i: $number\ of\ passengers\ taken\ from\ airport\ i$

F_k: $fixed\ cost\ of\ aircraft\ k$

R_k: $cost\ per\ mile\ of\ aircraft\ k$

$\theta\ :\ earliest\ time\ to\ serve\ on\ airport\ i$

$\varphi\ :\ latest\ time\ to\ serve\ on\ airport\ i$

$\aleph$: $average\ service\ time\ of\ airport\ i$

H_{ij}: $time\ needed\ between\ airport\ i\ to\ j$

$M\ :\ big\ number$

$\boldsymbol{Decision\ Variables}$

$$A_{ijk} = \begin{cases} 1\ , if\ aircraft\ k\ flies\ from\ airport\ i\ to\ j \\ 0, \qquad\qquad\qquad\qquad Otherwise \end{cases}$$

$$U_k = \begin{cases} 1\ , if\ aircraft\ k\ is\ used \\ 0, \qquad\qquad Otherwise \end{cases}$$

$\omega_j \; = \; Arrival\, time\, of\, airport\, j$

The objective functions

Objective function 1 (Z1)

$$Min\ \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{K} D_{ij}\, R_k A_{ijk} + \sum_{k=1}^{K} F_k\, U_k\ \ x_{ij} \tag{5.23}$$

Objective function 2 (Z2)

$$Min\ \sum_{j=1}^{n}\sum_{j=1}^{n} \omega_j + \aleph_j x_{ij} \tag{5.24}$$

$Subject\ to$;

$$\sum_{k=1}^{K}\sum_{j=1}^{n} A_{ijk} = 1 \qquad i \neq 1 \tag{5.25}$$

$$\sum_{k=1}^{K}\sum_{i=1}^{n} A_{ijk} = 1 \qquad j \neq 1 \tag{5.26}$$

$$\sum_{j=1}^{n} A_{1jk} = U_k \qquad k = 1, \dots, K \tag{5.27}$$

$$\sum_{j=1}^{n} A_{j1k} = U_k \qquad k = 1, \dots, K \tag{5.28}$$

$$\sum_{i=1}^{n} A_{iyk} = \ \sum_{j=1}^{n} A_{yjk} \quad k = 1, \dots, K\ and\ y = 2, \dots., n\ and\ i, j \neq y \tag{5.29}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{n} Y_i\, A_{ijk} \leq P_k U_k \qquad k = 1, \dots, K \tag{5.30}$$

$$A_{ijk} + A_{jik} \leq 1 \qquad k = 1, \dots, K\ and\ i, j = 2, \dots, n \tag{5.31}$$

$$\omega_{jk} \leq \varphi_j\ and\ \ \omega_{ik} \geq \theta_i \tag{5.32}$$

$$\omega_j \geq \omega_i + H_{ij}A_{ijk} + \aleph_i - M\left(1 - A_{ijk}\right),\ i, j = 1, \dots, n\ \ and\ k = 1, \dots, K\ also\ i \neq j \tag{5.33}$$

$$\omega_j \geq \omega_1 + H_{1j}A_{ijk} \qquad j = 1, .., n\ and\ k = 1, \dots, K \tag{5.34}$$

$$A_{ijk}, U_k \in \ \{0,1\} \tag{5.35}$$

$$\omega_{jk}\ \geq 0 \tag{5.36}$$

In the objective function, Eq. 5.23 minimize the total route cost of flight legs Eq. 5.24 minimizes the total processing time of the vehicles assigned to the route. In the constraints, Eq. 5.25 and Eq. 5.26 allow all nodes to be navigated once and with only one plane. Eq. 5.27 allows each vehicle to start the tour from the hub airport. Eq.

5.28 ensures that all vehicles return to the hub. Eq. 5.29 guarantees that each vehicle leaves the last arrival airport. Eq. 5.30 is the capacity constraint and ensures that the amount of passengers collected along a route does not exceed aircraft capacity. Eq. 5.31 is a constraint that prevents the aircraft from making sub tours (sub tour elimination). Eq. 5.32 ensures that the arrival time at the airports is between the earliest and the latest start times. Eq. 5.33 provides the calculation of arrival times by considering transportation and service times. Eq. 5.34 calculates the arrival time of the airport, which is the first stop, considering the transportation time only after the aircraft leaves the hub airport. Eq. 5.35 and eq. 5.36 are sign criteria.

5.14.1 Cost and Capacity of Aircrafts

As mentioned in the previous chapters, the A220 was first selected for make domestic flights. Capacity for A220 aircraft is limited to 120 passengers. As a fixed cost, 1500TL per plane and 1.5TL cost per passenger kilometer were created. Although many different sources have been used in the creation of cost per kilometer, many studies have been used to determine the airline costs according to aircraft types. During these investigations, it was found that the fuel consumption of the aircraft was primarily dependent on the body type and the type of engine used. Seat placement also has a great impact [127].

5.14.2 Distances and Times Between Airports

Flight times between airports were determined and used via Google maps. The distance between airports is the same as the p-median hub location problem. The earliest and latest service periods and average service periods of the airports are determined in proportion to their size.

The earliest service time is fixed at 08:00. Although service times do not fully reflect the reality, it is an important factor for initial solution and initial idea acquisition. However, by using these solutions and changing demand conditions, future flight schedule improvements and flight descriptions can be made. For a newly established airline, it can be said that the route currently being applied is feasible. It is also possible to search for a balance between day and night flights. This is because flight restrictions are different for cabin crew for day and night flights and fare rates may vary. However, this issue has not been examined currently. Airports and the times used for these airports are given below. Solutions and scenarios of the model are explained in detail in Chapter 6.

Table 5.9 Service times of airports

Airports	Earliest time (Hour)	Latest Time (Hour)	Service duration (minute)
ADA	08:00	18:00	20
ADB	08:00	18:00	25
ASR	08:00	18:00	15
AYT	08:00	18:00	25
BJV	08:00	15:00	25
DIY	08:00	20:00	25
DLM	08:00	18:00	20
ERZ	08:00	18:00	20
ESB	08:00	18:00	35
EZS	08:00	18:00	20
GZT	08:00	20:00	20
IST	08:00	00:00	45
KSY	08:00	20:00	20
MLX	08:00	20:00	25
SAW	08:00	22:00	30
TEQ	08:00	18:00	25
TZX	08:00	20:00	25
VAN	08:00	20:00	25

Table 5.9 shows the time window intervals defined for flights in the designed network. The operation time of the first planes for all provinces was determined as 08.00. The return times of the designated airplanes from the provinces they have visited are determined by considering the transportation possibilities in those provinces.

5.15 Multiple Traveler Travelling Salesman Problem (mTSP) for Construction of Flight Network

Another approach has been tried to compare costs and to predict the consequences of problems. This method is the traveling salesman problem approach. The traveling salesman problem (TSP) is a combinational optimization problem that has been studied extensively in the literature. It is the problem of returning a certain number of visit points starting from one point and visiting all points once in a way that minimizes the total lap length. Classical vehicle routing problem is the most popular of combinatorial optimization problems and is generally generalized as traveling salesman problems [129]. Classical vehicle routing problems are divided into two as symmetric vehicle routing problems and asymmetric vehicle routing problems.

Multi Travelling Salesman Problem (mTSP) is the same problem designed so that travelers are more than one. mTSP is same version of the travelling salesman problem (TSP) and can be defined as the problem of visiting cities (customer points) having to return to the starting point in a certain period of time with multiple travelers. This approach can be used in many ways in the routing of vehicles and the determination of the visiting points. The main reason for the design of the problem with mTSP is that the difference between aircraft flying from a base point and direct flying between nodes can be seen. The model used for the mTSP problem is given below [129].

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} \partial_{ij} N_{ij} \tag{5.37}$$

$$Subject\ to\ ;$$

$$\sum_{i=1}^{n} N_{ij} = 1,\ j = 2,..,n\ ,\ i \neq j \tag{5.38}$$

$$\sum_{j=2}^{n} N_{ij} \leq 1,\ i = 1,..,n\ ,\ i \neq j \tag{5.39}$$

$$\sum_{j=2}^{n} N_{1j} = m,\ j = 2,..,n \tag{5.40}$$

$$\sum_{i=2}^{n} N_{i1} = m,\ j = 2,..,n \tag{5.41}$$

$$\mu_i - \mu_j + nN_{ij} \leq n - 1\ ,\ i,j = 2,..,n,\ i \neq j \tag{5.42}$$

$$\aleph_{ij} \in \{0,1\},\ i,j = 1,..,n,\ i \neq j \tag{5.43}$$

Here, TSP model is a basic model. If we draw picture of that problem it's possible to say, let's consider a network of n nodes. i, j are the airport indexes. Variable ∂_{ij} refers the distance between airports. Variable N_{ij} is 1 if airport i precedes airport j in a route of the vehicle and $\aleph_{ij}$ is 0 otherwise. Then, variable μ_i used where i between 2 and n that based on well-known Tucker's formulation of subtour elimination constraint for traveling salesman problem.

Where, the objective function Eq. 5.37 models the total distance of aircraft route. Eq. 5.38 ensure that the m aircrafts enters to every airport and constraints Eq. 5.39 ensure that the aircraft does not need to depart from every airport, because the route ends after serving the last of them. Constraints Eq. 5.40 ensure that the aircraft starts its route exactly once and Eq. 5.41 ensures that all aircrafts which is trats its tour exits and constraints Eq. 5.42 avoid the presence of sub-tour. At last, Eq 5.43 is sign constraint of model. Model is based on the shortest possible distance and the lowest flight cost, making it possible to fly to all routes. Distance matrix used for the model and designated airports are the same.

This model is constructed as the 5th scenario. Established model fulfills the basic principles and is initial model. It basically tries to reach the optimum according to shortest path principle. Three assumptions were made within the model. Assumptions are about maintenance centers where assumed that is located in Istanbul, Antalya or Trabzon respectively. This will change the starting and ending points of the tours, which will change their path additionally. Changing routes affect the amount of aircraft used and the number of airports to be visited. Change in number of stopping airport points will directly affect the cost as it will change the total flight time and distance. Since the number of factors that can affect the model depends directly on determined routes, these variations of model have been created. It is aimed to determine routes with minimum cost by comparing results obtained through determined variations.

CHAPTER 6

COMPUTATIONAL ANALYSIS AND RESULTS

In this section, the results obtained from the problems of fleet selection, hub point selection and flight schedule formation are presented as a whole. The results were analyzed and explained under the scenarios. Models were solved by using licensed GAMS 24.1 program and CPLEX solver. Models were solved using a computer with Intel i7 2.00 GHz processor and optimum results were obtained. In the light of the results obtained from the text mining procedure, the results of the fleet selection section created with the help of multi-criteria decision making techniques and then flight location scheduling in addition to the hub location selection problem were examined.

6.1 The Results of Hub Location Problem

In order to determine the hub location, p-median hub location problem was studied. In this context, Turkey's demand of customers from different regions and from regions where population density is selected airports too. Information about airports is given in Chapter 5.

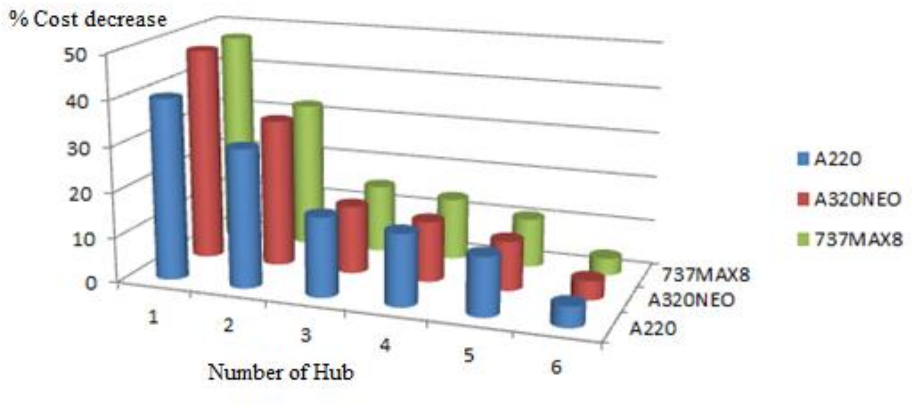


Figure 6.1 The effect of fleet and number of hubs on price change

In the constructed model, the behavior of the constraints is examined and explained with a Table. Capacity restriction was not used when developing the model. The main reason why the capacity constraint is not used is the idea that a small volume low cost airline carrier cannot initially generate a large demand in the beginning. Based on this idea, the effect of aircraft types on the selection of hub locations was investigated and minimum cost was considered. Figure 6.1 shows the effect of the change in the number of hubs and fleet type on the total cost decrease.

Table 6.1 Computational statistics of hub location problem

Number of Equations	Number of variables	Non-zero Elements	CPU Time(sec)	Used CPU
7346	11683	47179	0.078	6 MB

Table 6.1 shows the CPU time and used CPU capacity, which vary depending on the properties of the system used for solving the problem, as well as the equations and variables used in the hub location selection problem. The problem was solved in a short time and a small amount of CPU was used. The problem being solved easily is an example of the intelligibility of the coded model.

Figure 6.1 show the effects of the change in fleet type on the total cost reduction includes striking results. This is because the cost characteristics of the 737MAX8 aircraft and the A320NEO aircraft have similar characteristics, while the A220 fleet is significantly more efficient and economical. It is also among the results that the costs decreased as the number of selected hubs increased.

Table 6.2 Real value of hub selection cost

	# of Hub	A220	A320 NEO	B737MAX8
Cost	p=1	698 Mn	915 Mn	915 Mn
	p=2	419 Mn	483 Mn	483 Mn
	p=3	291 Mn	325 Mn	326 Mn
	p=4	240 Mn	276 Mn	277 Mn
	p=5	202 Mn	239 Mn	239 Mn
	p=6	176 Mn	213 Mn	213 Mn

p=7	168 Mn	204 Mn	205 Mn
p=8	INF	INF	INF
p=9	INF	INF	INF

Table 6.2 shows the values of the selection costs of hub points. INF means infeasible. However, the cost reduction slows down if the number of hubs is more than 3. Up to 6 hubs can be selected. If the number of hubs is more than 6, the model becomes infeasible. Since the cost reduction rate slowed down because the number of hubs was more than 3, the number of hubs was determined as 3. Minimum feasible cost is released in the case of a hub point assignment for the value of p is 6, the number of hubs has been tried to be kept to a minimum since the flight network is starting to break from the hub and spoke methodology.

Data on this process are described in the relevant section. Establishment of a heterogeneous fleet airline has not been made a priority. The main reason for this is that pilot requirements in the heterogeneous fleet and training costs put an extra burden on the investor's budget. However, it is clear that a heterogeneous fleet system to be formed with the specified aircraft types would be more costly than a homogeneous fleet system using the A220 aircraft. In addition, the compatibility of the A220 airplane with the existing infrastructure of all selected airports eliminates the extra costs and penalties in the model. When all these reasons are taken into consideration, Antalya, Istanbul and Trabzon international airports have been designated as the main hub and other airports have been connected to serve these hubs.

Aircraft selection and fleet planning are expensive investments in addition to construction of new airports or infrastructure improvements, and it is extremely important that decisions to be made on these issues be based on scientific reasons. Because the return of the investments to be made in line with decisions taken in a short time and the success of the enterprise depends on the degree of accuracy of these decisions. Airline should plan its resources well and shape its future investments in this direction. Formation of flight network and fleet planning are processes that need to be handled together. These processes need to be updated with changing conditions.

The aim of this study is to add new dimensions to hub transportation problems in terms of air transport and to guide optimum use of the available resources especially for airline and passenger transport. When hub allocation problems are examined, it is seen that distances between nodes, flow quantities and unit transportation costs are taken into consideration. However, it has been determined that unit transportation costs cannot be used due to lack of data especially in applications in the field of aviation. In this study, it is revealed that unit transportation costs are one of the main determinant factors in hub allocation especially for aviation sector and it is absolutely necessary to use it.

When hub location problem types are examined; one of these problem types in fixed cost hub placement problems; it is seen that infrastructure costs (as fixed costs) are taken into consideration in determining number of Hubs and location and assignment of Hubs, but they are not taken into consideration in p-hub median problems. However, the ability of any aircraft to take off and landing from a runway depends on suitability and adequacy of the runway.

It would be pointless for model to designate an airport as a hub where an airplane cannot take off and landing. Therefore, infrastructure needs to be improved, which will incur additional costs. In this study, the objective function for all types of problems is arranged to take into account infrastructure costs of runways. According to analyzes made in Chapter 5, infrastructure cost affects especially the total cost.

As mentioned above, distance is one of the basic parameters considered in hub location problems. Model selects and assigns hub locations based on the distance between origin and destination points. Since aircraft is used as a connecting line in aviation, the range of the aircraft becomes important at this point. If distance between node-hub and hub-hub determined by the model is higher than range of aircraft to be used, it is not possible to use this type of aircraft on the specified lines.

In studies conducted to date, it has been determined that range constraint of aircraft is not taken into consideration in hub placement problems. Therefore, it was seen that range constraint of aircrafts should also be taken into consideration in model. Costs required to improve airports are quite high. For this reason, a passenger traffic continuity constraint has been added to prevent the assignment of these airports as hubs in model whose passenger traffic does not show continuity during the year.

Thus, it is restricted to designate an airport as a hub without continuous passenger traffic. In this study, it has been seen that it would be a proper approach to designate airports as having hubs with a certain amount of passenger traffic and having continuity and to invest in these airports if necessary. In addition, this approach increases the percentage of aircraft use by passengers who can be transported during the year and affects profitability.

In this study, it is seen that unit transportation costs and some performance characteristics of aircrafts affect the hub location selection and assignment as mentioned above. In addition, it is known that flight network and fleet planning are the processes that should be performed together. From this point of view, it is determined that hub location problem and aircraft fleet selection (in a sense, fleet assignment) can be handled as a sequenced problem. An airline that wants to transport passengers can use fleet selection, hub location selection and flight routes planning using models proposed in the study.

Likewise, an airline company that plans to carry out passenger transport can determine appropriate aircraft to minimize its total costs by carrying out these analyzes prior to aircraft purchase. In conclusion, considering the dynamics of air transport in the study, it has been provided to transform problem into a more realistic and usable structure by airline processing with changes in purpose function of previously developed models and newly added constraints. In other words, more general hub location problem has become more specific for air transportation.

Proposed models can be analyzed for decision making problems such as determining fleet of trucks and determining capacity of hubs to be opened in road cargo or passenger transport. In addition, the applicability of road or combined (airline-road) cargo or passenger transport can be examined. In addition, this thesis is first study to model designed for domestic passenger transport in Turkey, carries a feasibility feature for the new airline will be established.

6.2 The Results of Flight Network Design

Starting with the selected fleet type, establishing the flight network by using the selected main hub points and determining the amount of aircraft required and the results are explained in this section. In the first stage, when the flight network is modeled, vehicle routing problem with time window was considered. Basic model for routing problem is homogeneous fleet routing problem consisting of A220 type aircraft.

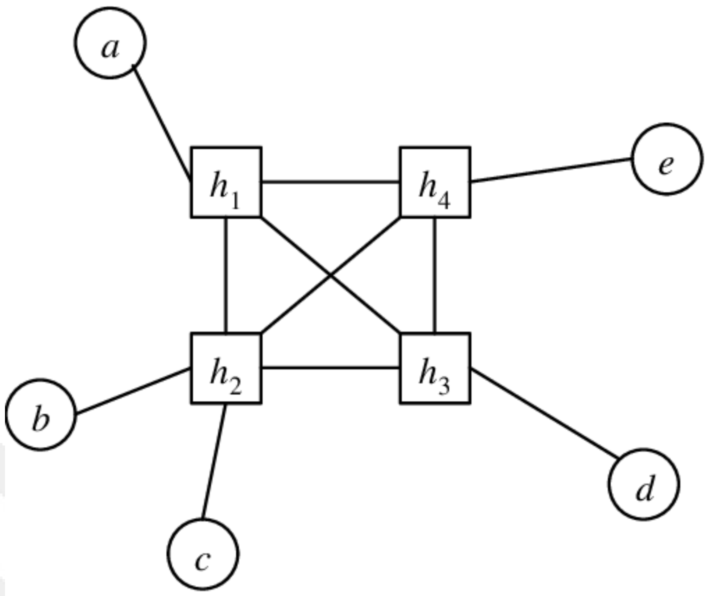


Figure 6.2 The single hub assignment flight network

As shown in Figure 6.2, all assignments are performed only through nodes connected to hubs. As shown in Figure 6.2, all assignments are performed only through nodes connected to hubs. For example, if you want to travel from point a to point e, you will have to follow the route a-h1-h4-e, respectively. Since this approach is used, the appointments in the eastern provinces have not been realized due to the shortage of demand and the very close distances due to exceeding the maximum working time. Even if appointments are made, the flights will be multi-stop and long, so there will be no reason to prefer. For all these reasons, no assignment has been made to ERZ, EZS, KSY and TEQ airports fır daily flights. However, according to changing demand conditions and regional transportation trends, it is possible to set up daily flights in the future.

Main purpose of using time windows is to create possible flight dates and times when vehicles are assigned to routes. The visibility of flight times will also give an idea of the number of cabin personnel required. However, a few problems were encountered when the model was constructed and run. The most important of these problems is the lack of daily flights to some airports due to low daily demand. Daily flight routing problem with time windows does not meet the Hub-node-Hub priority in this circumstance. For this reason, direct flights were allowed on some flights, while the frequencies were reduced and daily flights were not allowed on some flights. Routes obtained from the model, the duration and frequencies of the routes are given in the Table 6.3 below.

Table 6.3 Single assignment homogeneous fleet daily flights

Aircraft	Daily Flight			
1(Black)	AYT-ADA	ADA-AYT	AYT-IST	IST-AYT
2(Red)	AYT-SAW	SAW-AYT	AYT-DLM	DLM-AYT
3(Orange)	AYT-BJV	BJV-AYT	AYT-ASR	ASR-AYT
4(Yellow)	AYT-TZX	TZX-AYT	AYT-GZT	GZT-AYT
5(Green)	TZX-IST	IST-TZX	TZX-MLX	MLX-TZX
6(Blue)	TZX-DIY	DIY-TZX	TZX-VAN	VAN-TZX
7(Purple)	IST-ESB	ESB-IST	IST-ADB	ADB-IST

As seen from Table 6.3, it is deemed appropriate to place 1 daily flight to these cities in line with the demands. 8 hours of flight is placed in accordance with the cabin staff does not exceed the working hours and does not cost extra. However, it is not possible to set up at least one frequency flight per day, especially due to low passenger demands in the southeast provinces. At this stage, the framework that is considered when designing the flight network is shown in Figure 6.2.

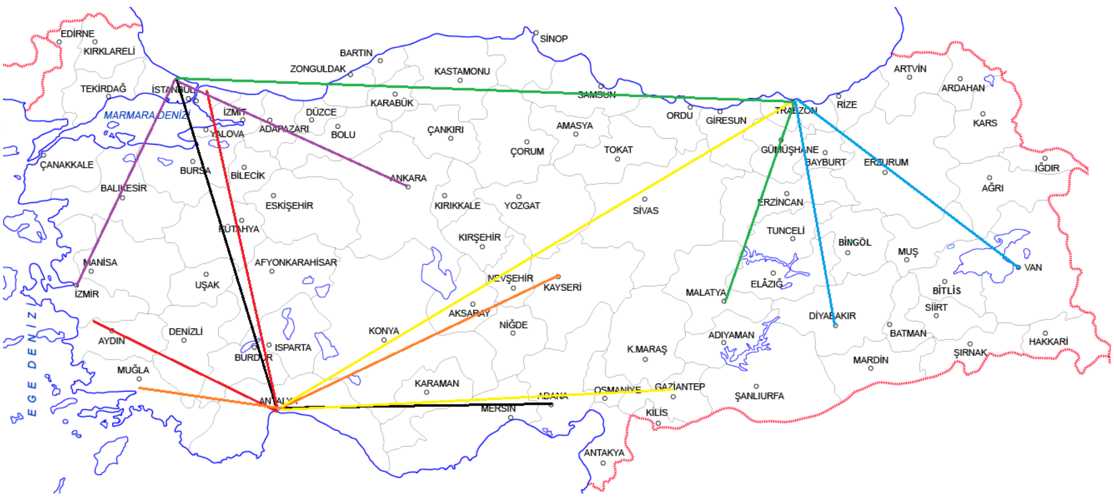


Figure 6.3 Single hub assignment with homogeneous fleet daily flight map

Figure 6.3 illustrates daily reciprocal flights for a single-assignment homogeneous fleet problem. Each color represents an airplane.

Table 6.4 The comparison of the objectives

Objective Function	Total Cost (TL)	Avg.Flight hours	# of Aircrafts
Multi-objective Model	18210	275 min	7
Minimum Flight hour model	19015	267 min	8

As it is seen in Table 6.4, during the comparison of objective functions, it is seen that the optimal result in homogeneous fleet routing problem is in multi-objective model. The main reason for this situation is that direct flights are assigned to airplanes due to the low demand in the eastern provinces for minimum cost flights. As a result, the flight time per aircraft has increased. However, the direct flights assigned to the eastern provinces do not stop at hubs, resulting in extra costs arising from unused capacity.

Therefore, weekly flights should be used instead of daily flights in these provinces. It is also possible to use a system and operate a fleet model where all nodes can fly to all hubs in order to reduce flight time and make more flights which also called as multiple assignment hub location. However, in the assignments made using homogeneous fleet with multiple hub assignment, there were no difference from the previous model. Outputs from the heterogeneous fleet model constructed using the multiple assignment model are described below.

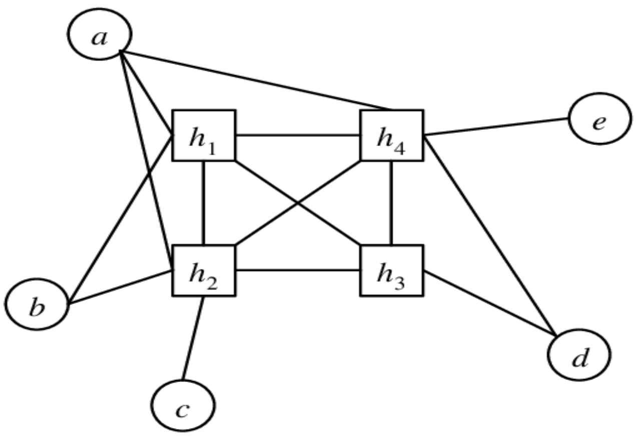


Figure 6.4 Multiple hub assignment flight network

Figure 6.4 shows obvious points that differ from the previous network structure used. The most important of these points is that the node points can use any hub point. This reduces the number of connecting flights and shortens the flight time relatively. For example, as in the previous scenario, a passenger who wants to go from point a to point e will use the route a-h4-e and will not have to stop at hub h1. However, according to the scenario, when multi-assignment routing is performed using homogeneous fleet, total cost and routes have not changed. Thus, the multi-assignment model with the heterogeneous fleet was constructed and solved. It can be seen that solved model does not assign to some points. This is due to the cost of flying from those points. Because vehicles used in heterogeneous fleet become more costly as the distance increases.

Table 6.5 Multi assignment heterogeneous fleet daily flights

# of Aircraft	Aircraft	Airport1	Airport2	Airport3	Airport4	Airport5
1	A220	AYT➔	SAW➔	AYT➔	-	-
2	A220	AYT➔	BJV➔	ADA➔	AYT➔	-
3	A220	AYT➔	GZT➔	TZX➔	ASR➔	AYT
4	B737MAX8	IST➔	ADB➔	AYT➔	IST➔	-
5	B737MAX9	AYT➔	DLM➔	IST➔	AYT➔	-

Table 6.5 shows the airports in which multi-assigned airplanes must stop. In the analysis using the multi-assignment model, it was observed that the daily flight amount and cabin crew requirement increased. However, in the model where all of the nodes can use all hubs without direct switching between nodes using multiple searches, the number of flights decreased but the cost increased. In this system, the total cost of all flights was 31.329 TL. This change led to a cost increase of approximately 72% in overall operations.

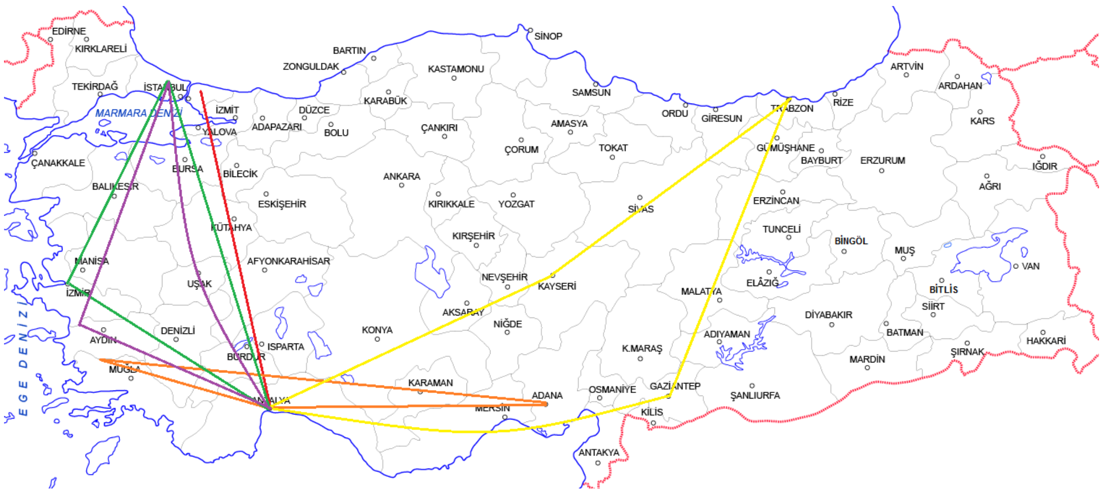


Figure 6.5 Multi assignment heterogeneous fleet daily flight map

Figure 6.5 shows daily reciprocal flights for a multi-assignment heterogeneous fleet problem. Each color represents an airplane. Considering all these results, it should be noted that the number of passengers carried has been increased and therefore the capacity of the airline has been increased. There are also positive effects caused by cost increases. Cost and fleet information for all scenarios are summarized in Table 6.6 below.

Table 6.6 Scenarios for designed fleet type and assignment

Sneraio for Network design problem	**Daily Cost (TL)**	**The number of aircrafts**	**The assigned aircraft**
Single Assignment Homogeneous Fleet	18210	7	A220
Single Assignment Heterogeneous Fleet	24204	8	A220, B737MAX8
Multi Assignment Homogeneous Fleet	18440	7	A220
Multi Assignment Heterogeneous Fleet	31329	5	A220, B737MAX8

When four scenarios examined in Table 6.6, it is possible to see the change in cost and fleet information. However, the other issue to be examined is the total flight amount and the cabin crew requirement.

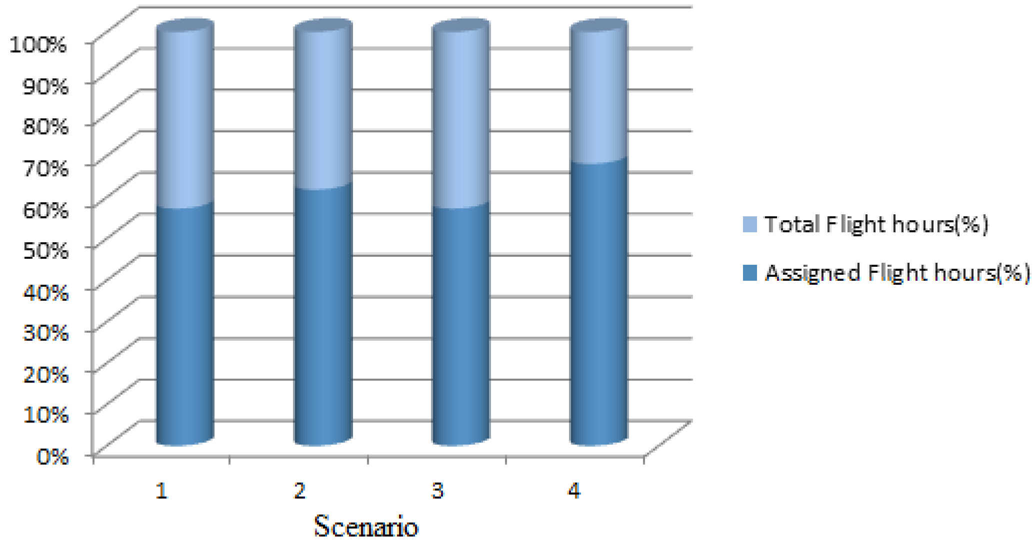


Figure 6.6 Percent usage of total flight hours in all scenarios

As can be seen from Figure 6.6, under all scenarios, no aircraft assigned to routes could use more than 68 percent of the total flight time. One of the main reasons for this situation, Turkey is not found to be too close to each other due to the wide geography of the city. However, flights can be made more efficient by selecting airports that are distant from each other and have high passenger density. In addition, the types of aircraft used can be further reduced, reducing costs per aircraft and increasing the duration of aircraft use. Flight times obtained from the four test problems given as scenarios are given below in Table 6.7.

On the other hand, design of flight network, which includes both time window approach and the subsequent hub selection problem, is an important step in thesis. The main success of model is to increase aircraft utility percentage of airline that will only serve domestic flights up to 68%. Referring to Turkey in serving other airlines, it does not have only airline serving for domestic routes. Looking at existing airlines, it can be seen that percentage of aircraft use is around 80%. Although the results of model are quite low according to these airlines, it should be noted that these companies perform international flights additionally. When international flights are added to this network, it can be said that percentage of aircraft utility will reach 80% threshold in terms of both flight time and flight kilometers easily.

Table 6.7 Total flight hours of all test scenarios

Scenario	Total Assigned Flight Hours (min)	Total Allowed Flight Hours (min)
Scenario-1	275	480
Scenario-2	297	480
Scenario-3	275	480
Scenario-4	327	480

In the scenarios created in Table 6.7, it is seen that all models use at least 57.2% of the possible flight time. However, more than 68.2% of the total time could not be used. On the other hand, determination of daily flight routes and aircraft quantities shed light on the required cabin personnel as well as the daily cost. In the optimal solution, a total of 7 aircraft were used with the homogeneous fleet single assignment hub model according to the amount of aircraft specified. Aircrafts used belong to the narrow-bodied jet family.

Cabin crew requirement in the aircraft is determined by the seat arrangement and the number of emergency exits [128]. Since there are a total of 4 emergency exit doors in narrow body jets, in case of emergency, a flight attendant should be assigned to each gate. From this idea, it can be interpreted that there should be at least 4 cabin attendants in narrow body jets. Considering that each aircraft flies with 2 pilots, a total of 6 personnel are required for one aircraft.

Since there are 7 aircraft in the fleet, there must be at least 14 pilots and 28 cabin personnel in order to perform all flights. However, these conditions are true if a person is assumed to work all days of the week. Since it is prohibited by law for a person to work every day of the week, it can be inferred that the required staff is more than 42 in total. It is clear that the team cost will be even higher, given the assignments made by the heterogeneous fleet. Because a pilot cannot fly two aircraft with different cockpits, training and rotation costs will be high.

Another important issue is that the selected hub centers and aircraft types are also suitable for international flights. These aircraft in Turkey, have not reached the maximum allowable flight hours in support of this claim. It is also possible to carry out international flights if the fleet is likely to grow in the future.

According to the results, passengers from 18 airports can be reached by a total of 7 aircraft. The total cost of the routes is minimum 18,210TL and all vehicles return to Antalya hub until 20:00, Trabzon hub until 24:00, so that they can continue to be used for future international flights. Since the number of selected airports depending on Istanbul Hub point is small and there are 2 main airports which can be sufficient for the demands, it is assumed that the flights are performed directly. In the completed flight network study, the routes for direct daily flights are schematized. Schematized daily flight routes are shown in Figure 6.5 below.

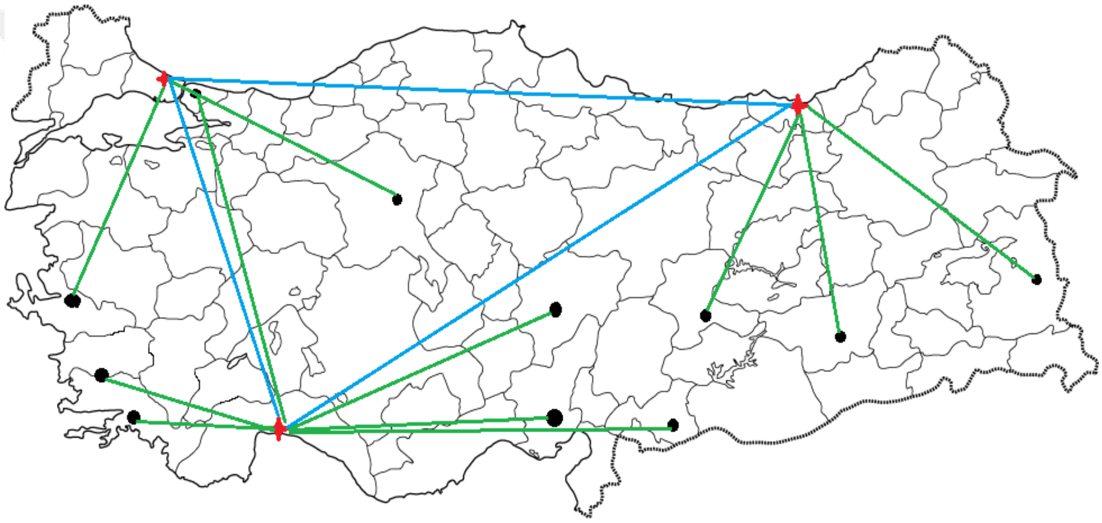


Figure 6.7 The optimal daily direct flight routes scheme

In Figure 6.7, optimal daily direct flight network is shown. Airports selected for problems not cover all airports operate in Turkey, so it can be seen as a pilot study. Since increasing the number of airports will increase the complexity of the study, the probability of reaching a solution and the solution times will be extended. Daily flight network with the airports included in study is shown.

Table 6.8 Overall computed statistics of test scenarios

Assignment Type	**Single-Hub**		**Multi-Hub**	
Fleet Type	Homogenous	Heterogeneous	Homogenous	Heterogeneous
Number of Equation	3527	1700	10934	5270
Number of variable	1405	672	4356	2083

Non-zero Element	16012	7574	49637	23479
CPU Time	1.3 sec	0,89 sec	2,1 sec	1,7 sec
CPU used	8 MB	7 MB	12 MB	11 MB
Status	Optimal	Optimal	Optimal	Optimal

Table 6.8 shows computational statistics of all problems in order to compare the generated problems and make inferences. At first glance, it can be said that as the complexity of the problems increases, the amount of CPU required and the solution time increase. In addition, as the number of criteria increased, the equation and variable used increased. Furthermore, since the changes in the amount of aircraft used impose different obligations on its own, additional constraints and variables have been added to the models.

In heterogeneous fleet solutions, the number of variables and amount of equations decreased due to change in capacity values of the aircraft used. In heterogeneous fleet solutions, the number of variables and the amount of equations decreased due to the change in the capacity values of the aircraft used. However, the increase in capacity brought additional costs. This increased the total cost and satisfactory values could not be reached although optimal solutions were achieved. On the other hand, open tour TSP, which is used as an instance to test the hub network, showed different results. Figure 6.6 shows the flight network designed as a result of the TSP problem.

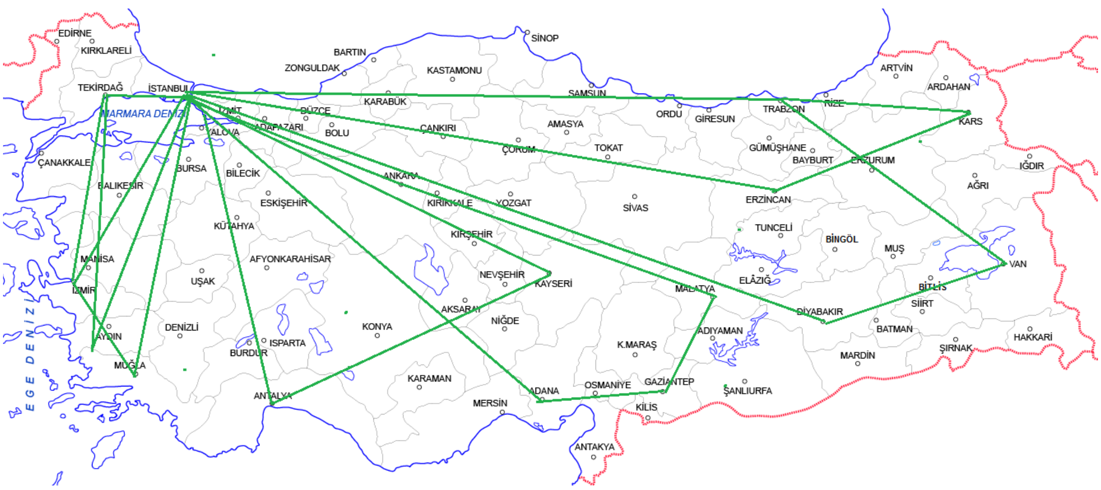


Figure 6.8 Created flight network with mTSP on Istanbul

As shown in Figure 6.8, mTSP modeled flight network is schematized. According to the model, at least 7 planes are required and each plane visits a minimum of 3 cities.

All routes have been reached and flights have been made to each point. However, the service times of some of the flights are outside the period that can be flown with a single cabin crew.

This situation makes it difficult to plan connecting flights, except where flights can be made directly. Apart from difficulties, it increases the amount of personnel needed. The increase in the amount of staff triggers the total cost increase. According to the data obtained from the solution of the problem, all flights during the day have a total length of 7712 kilometers.

When fixed and route costs of every aircraft used for t solution of designated problem are considered for homogeneous fleet, total cost is found as 22,068TL with a fixed cost of 1,500TL per plane and a fixed cost of 1,5 TL per kilometer. Although there are many scenarios that can be used in flight network design, the most accepted approaches are used and the results are obtained. Costs and distances are approximate, but converge to reality. The results were similar but not the same in all studies. One of the reasons why it is stable and good is that the problem is a small problem, although it is one of the hardest problems. Below is a graph showing the location of all problems in the total cost in Figure 6.8.

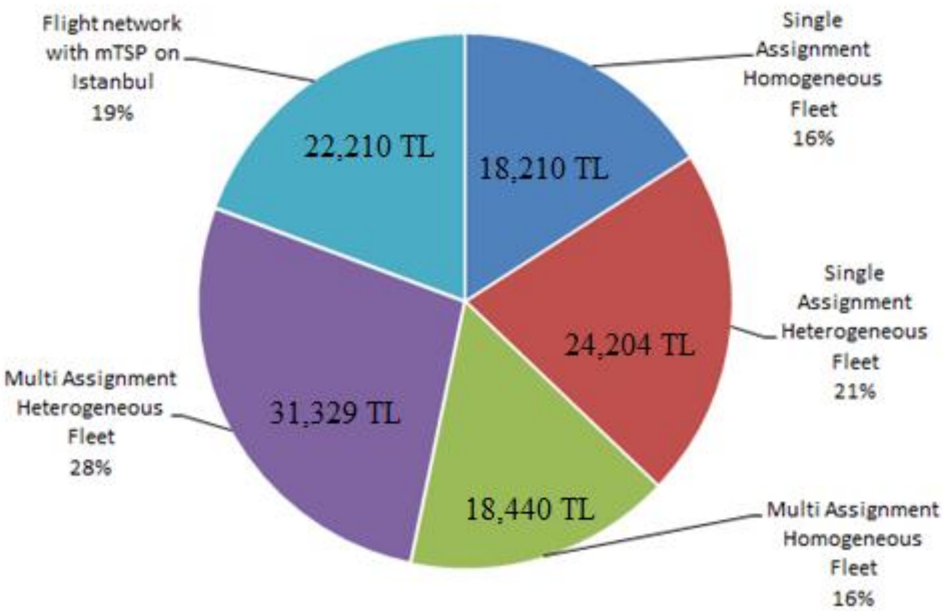


Figure 6.9 The share of all test problems in total cost

Considering the shares in total cost in Figure 6.9, it can be seen that costs of homogeneous fleet-generated problems are more reasonable. In this case causing factors are seen as being more heterogeneous fleet of aircraft used on short distances the cost of the infrastructure costs and the lack of suitable aircraft that due to all the airports in Turkey. Also, due to the geography of Turkey is not a country that host long-range flights.

Flat flight times on flights are therefore less. Low flight time triggers cost increase. When examined carefully, it was seen that TSP approach gave a better result than two of the approaches modeled with hub and spoke methodology. Therefore, other airports selected as hubs for TSP approach were also selected and implemented. In these assumptions, presence of the main maintenance centers in Istanbul, Antalya and Trabzon provinces were taken into consideration. In addition, it was taken into consideration that the aircraft started flights from these provinces respectively. In this case, a separate application was made for the location of ANKARA located in the middle of all selected hub points and results were compared.

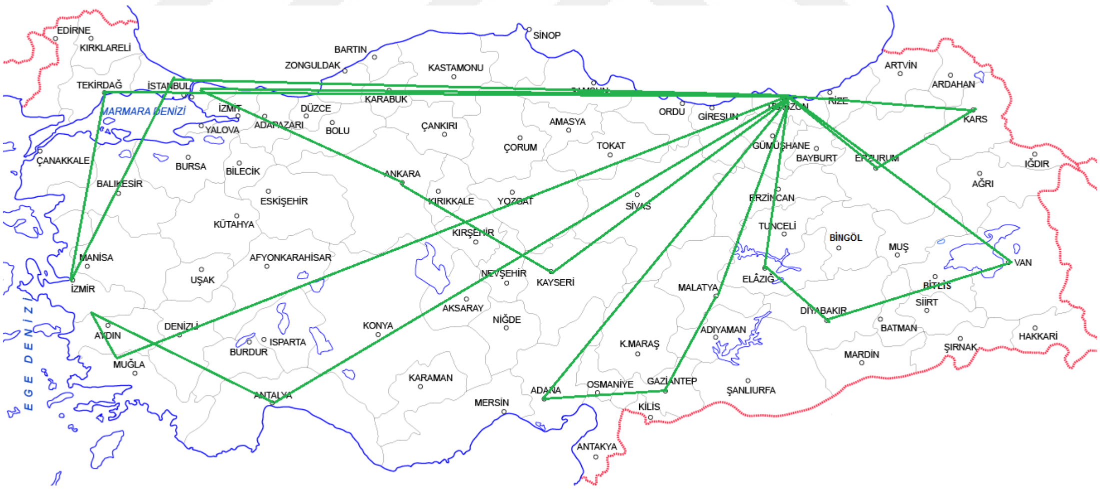


Figure 6.10 Created flight network with mTSP on Trabzon

As shown in Figure 6.10, mTSP modeled flight network is schematized. According to the model, at least 7 planes are required and each plane visits a minimum of 3 cities. All routes have been reached and flights have been made to each point. However, the service times of some of the flights are outside the period that can be flown with a single cabin crew. According to the data obtained from solution of problem, all flights during the day have a total length of 6517 kilometers. Total cost is reached as 20,276 TL

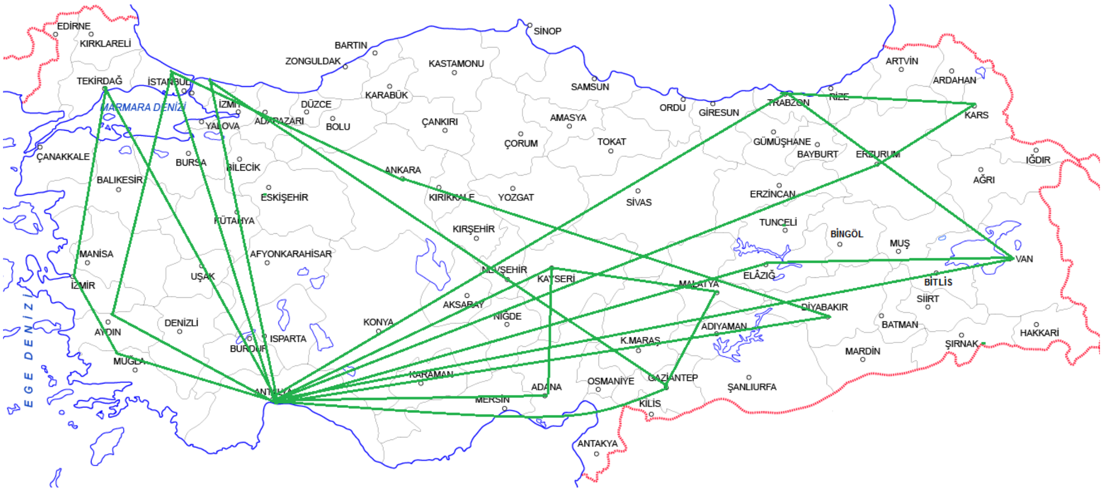


Table 6.11 Created flight network with mTSP on Antalya

As shown in Table 6.11, mTSP modeled flight network is schematized for Antalya. According to the model, at least 7 planes are required and each plane visits a minimum of 3 cities. All routes have been reached and flights have been made to each point. According to the data obtained from solution of problem, all flights during the day have a total length of 6334 kilometers. Total cost is reached as 20,001 TL. In all mTSP approach analyzes for selected hub points, costs were higher compared to other approaches. On the other hand, for ESB airport, which is considered the midpoint of all hubs, travelling salesman problem has implemented as additionally and shown in Figure 6.12.

Figure 6.12 Midpoint of the three selected hub locations

Main reason for making an implementation to the midpoint of central region in Ankara, also midpoint of Turkey is to minimize total distance traveled. In addition, Ankara is at an equal distance from all other airports. This minimizes the total mileage and cost of the tour. Figure 6.13 shows the mTSP flight network application for Ankara.

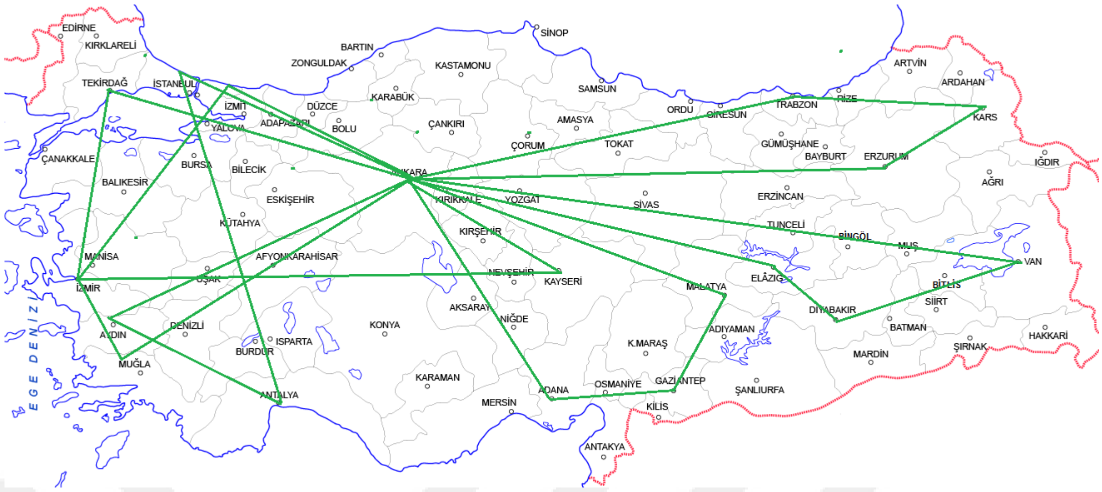


Figure 6.13 Created flight network with mTSP on Ankara

As shown in Figure 6.13, mTSP modeled flight network is schematized for Ankara ESB airport. According to the model, at least 7 planes are required and each plane visits a minimum of 3 cities. All routes have been reached and flights have been made to each point. According to the data obtained from solution of problem, all flights during the day have a total length of 5549 kilometers. Total cost is reached as 18,824 TL. In all mTSP approach analyzes for selected hub points, costs were lower compared to other hub points.

According to other hub point implementations, lower cost and with lower round kilometers to have reached in this approach which is caused by the presence of Ankara in central Turkey. Likewise, Ankara is at an equal distance from all other airports and allows equal flight times. Although it still appears to be more costly than the hub and spoke approach, the fact that it has the lowest cost among other TSP approaches may make Ankara a candidate for center of direct flight network design. In Table 6.9, detailed statistics of all test problems created with the TSP approach can be seen.

Table 6.9 Computational statistics of mTSP test problems

Main Hub	IST	AYT	TZX	ESB
Solution Time(seconds)	17	75	73	41
Status	Optimal	Optimal	Optimal	Optimal
Objective Value (kilometers)	7712	6334	6517	5549
Total Cost (TL)	22.068	20.001	20.276	18.824

When Table 6.9 is examined, the optimal solution is reached for all test problems. In addition, the results obtained and the cost amounts are within the acceptable range by comparing hub and spoke based model results.

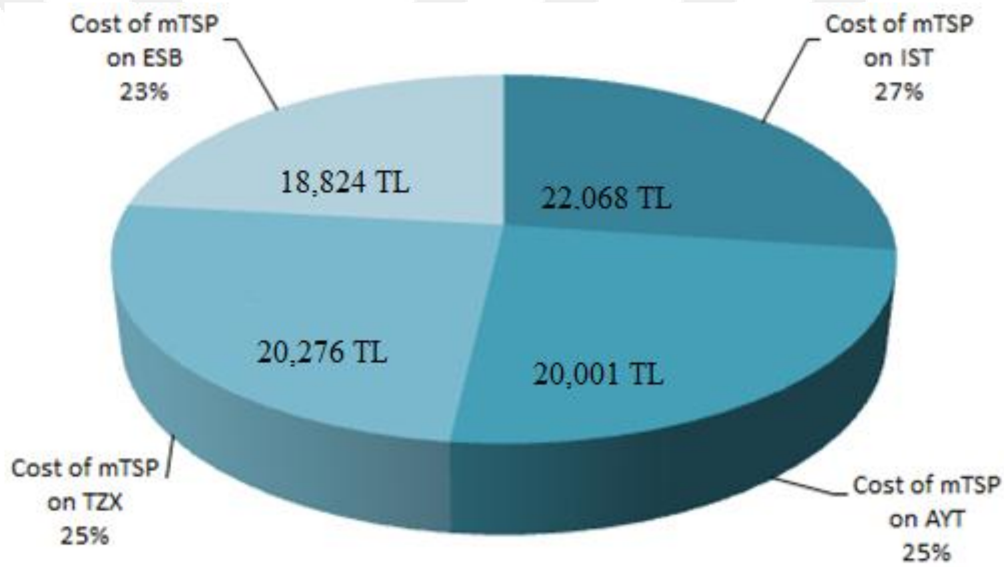


Figure 6.14 The share of mTSP test problems in total cost

When the comparison between TSP test problems is considered, it is clear that the lowest cost is reached in Ankara location in Figure 6.14. It is possible to design a flight network based on direct flight from ESB airport at a lower cost compared to other locations used. This makes the ESB airport the primary candidate if a network design with direct flights is to be made.

CHAPTER 7

CONCLUSION AND DISCUSSIONS

Increasing globalization, rapidly developing technology and changing customer demands have necessitated the change and development of supply chain transportation management approaches day by day. In order to stand out among the many competitors, companies try to increase the product range and quality of transportation activities and service speed. However, these activities increase the costs of firms and decrease the profitability. The two most important activities of logistics systems are storage and transportation. Improvements in these two areas of activity have led to a reduction in production costs and they contribute significantly to increase their satisfaction. For this reason, many academic studies have been carried out especially on distribution and flight network optimizations.

In this study, to be established in Turkey to operate domestic passenger carrier airline route network and aircraft selection problem considering the design was carried out. Optimum results were obtained in the models. With this model, hub location was selected among the selected 18 airports and a flight network was designed to meet the daily calculated demands. The designed flight network consists of routing single-assignment homogeneous fleet aircraft. With the hob-node-hub approach, an effort has been made to move the requested passengers from one airport to another as soon as possible with minimum cost. However, the results of the model contain controversial default results.

The main focus here is the controversial situation of the 737 MAX series aircraft. Boeing 737 MAX aircraft are manufactured differently from the pre-series aircraft to save fuel. The engines are larger, and also positioned ahead and above. Therefore, the aerodynamics of aircraft is quite different from the others. All airplanes have a sensor, called AOA (Angle of Attack), which controls the angle of the aircraft during manual flight. Due to the nature of the aircraft, the nose parts tend to rise. This is controlled by the MCAS (Maneuvering Characteristics Augmentation System). According to the information obtained from the accident report, the aerodynamics of this model has been changed to provide the AOA angle has become a little difficult and the system started to give error thinking that the wrong AOA. This caused the nose of the aircraft to be constantly raised by the MCAS system, causing the aircraft to fall and disrupt its aerodynamics. In fact, the main reason for the accident is hidden here. However, there are reasons why 737MAX series aircraft are preferred to A320NEO. The fact that aircraft operating costs are less than A320 NEO and fuel consumption rate is more efficient in heterogeneous fleet routing problems also support this situation [130]. The fact that this plane gained a bad reputation among the passengers due to public accidents and many dialogues between the manufacturer and countries has led many airlines to stop the flights of this model.

A real problem was examined in constructed models and the data were obtained from reliable sources and solutions were made according to these data. However, some assumptions were used during the solution. One of these assumptions is that changes in demand are not taken into account. There will be situations in which demand is uncertain in real life applications because the changeable demands have consequences that can directly affect the flight network.

In addition, it was assumed that all aircraft acted in accordance with the schedule and there were no delays or cancellations. Another assumption is that the aircraft data are not entirely real, but are derived from the engine type used by the aircraft. Therefore, it may be recommended to expand the model for cases where demand is uncertain. If the number of airports and aircrafts in model increases, solution of the model will takes a long time. For this reason, heuristic or meta-heuristic methods can be used for the solution of extended model. In addition, accessing the actual data of aircraft for a wider study will increase the reliability of the model being studied.

It is possible to summarize the differences of this master study from other studies conducted so far in terms of hub location problems as follows:

- Taking into consideration of infrastructure costs of airports by type of aircraft,

- Taking into consideration of unit transportation costs for each route according to aircraft type,

- Taking into consideration of flight distances between airports by considering altitude variable and air traffic routes,

- Use of real air passenger traffic data,

- Taking into account the range limit of aircraft,

- Adding the continuity constraint of cargo traffic.

In subsequent studies, the choice of aircraft type to be used between the p-hub median and routes can be performed integrated with hub loops selection problem and can be worked with more aircraft types. For the solution of extended problem, especially genetic algorithm, simulated annealing and tabu search can be considered. On the other hand, what make this work unique and special is the features listed below;

- Comprehensive study that made especially in Turkey for domestic air transportation.

- It is feasibility study for establishing new airlines for domestic air transportation in Turkey.

- It provides concrete information comparable to different approaches and fleet types.

-It can be compared with a wide range of studies around the world, as it is prepared with both a Hub approach and a direct flight network approach.

Furthermore, this study as a whole, is in the nature of a general review of aviation activities in Turkey offers a new and different perspectives. The changes in fleet design can be examined by selecting more than 2 aircrafts and calculating the relevant parameters and using the hub site selection and assignment model. Exchange of Turkey's population forecast for the next 20-year period and cargo data made possible settlement hubs identified. Reports may be submitted to the administrations on this matter.

In addition, this thesis carries the feasibility report feature the new airline may be established in Turkey. It started with determination of the types of aircraft required for the selection of hub locations and the determination of the hub locations and ended with determination of the routes. Approaches used in determining the routes are other interesting features of this thesis. Although it was designed using Hub and Spoke approach with time windows, the problems were designed and tested under the assumptions for the direct flight network. In comparison, each approach is planned under different scenarios and the results are discussed. Scenarios that are mainly considered when determining hub and spoke flight network are listed;

- Single Assignment Homogeneous Fleet

- Single Assignment Heterogeneous Fleet

- Multi Assignment Homogeneous Fleet

- Multi Assignment Heterogeneous Fleet

In order to discuss and evaluate the routes planned with these scenarios, basic form of the TSP approach is used to direct flight network scheduling with minimum route problem. TSP approach used is the multi-traveler version of the TSP problem, and each vendor represents one aircraft. Thus, two methods are compared which creating basic flight network under different scenarios and is scheduled for Turkey. It is possible to present the suggestions listed below in terms of future studies. At last, to be make more realistic of this study, following can be considered.

-The mathematical model can be worked stochastically to include the situations of uncertainty. Thus, much closer to the actual characteristics of the problem can be achieved.

-In the literature review, a mathematical model that considers hub location problems and vehicle routing problems is not found. By considering these two types of problems together, mathematical models can be developed for a large transport network problem.

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Yüksek Lisans	Endüstri Mühendisliği Yöneylem Araştırması Anabilim Dalı	Gaziantep Üniversitesi	2018-2020
Doktora			