JOURNAL OF AERONAUTICS AND SPACE TECHNOLOGIES
(ISSN: 1304-0448)
January 2020 Volume 13 Number 1
www.jast.hho.edu.tr

Research Article

Competitive Profiling to Evaluate Airline Hub Connectivity

Zeliha AKÇA[1]

[1] *Turkish Airlines, Genel Yonetim Binasi, Yeşilkoy Mah., Havalimani Cad., 34149, Yesilkoy, Istanbul, Turkey,* zelihaakca@gmail.com, https://orcid.org/0000-0003-3992-3198

Article Info

Received: *November 11, 2019*
Accepted: *December 31, 2019*
Online: *January 23, 2020*

Keywords: Competitiveness, Hub Connectivity, Profiling, Strategic Management, Airline

Abstract

This research develops a new methodology to calculate hub connectivity and to do strategic comparative analyses for airlines. This study utilizes a strategic management tool, a competitive profiling matrix, to design a measure that enables a profiling to reveal relative strengths and weaknesses of hubs. The measure is a result of the evaluation of various critical success factors representing key components to achieve a level of excellence in terms of connectivity. The methodology provides a unique perspective with the application of a strategic profiling method and defining a wide range of structural and practical success factors. Computational experiments based on real data as well as sensitivity analyses to appraise the qualitative side of the approach are included. Connectivity scores of six major hubs and the levels of excellence that they achieve in each factor are calculated. The results show that Istanbul hub of Turkish Airlines has the largest connectivity and overall results are comparable with the results presented in literature. Finally, sensitivity analysis proves that the methodology is not sensitive to the qualitative components of the approach, and efficiency analysis indicate that all hubs perform similarly and they need to improve their efficiency.

To Cite This Article: Z. Akca, "Competitive Profiling to Evaluate Airline Hub Connectivity", Journal of Aeronautics and Space Technologies, Vol. 13, No. 1, pp. 107-119, Jan. 2020.

Rekabetçi Profilleme Metodu ile Havayolu Aktarma Merkezinin Bağlantısının Ölçülmesi

Makale Bilgisi

Geliş: *11 Kasım, 2019*
Kabul: *31 Aralık 2019*
Yayın: *23 Ocak 2020*

Anahtar Kelimeler: Rekabet Edebilirlik, Aktarma Merkezi Bağlantı Değeri, Profilleme, Stratejik Yönetim, Havayolu

Öz

Bu araştırma, aktarma merkezi bağlantı değerini hesaplamak ve havayolu merkezleri için karşılaştırmalı stratejik analiz yapmak için yeni bir yöntem geliştirmiştir. Bu yöntem, bir stratejik yönetim aracı olan rekabetçi profilleme matrisi kullanarak merkezlerin göreceli güçlü ve zayıf yönlerini ortaya çıkarmaktadır. Elde edilen ölçek, bağlantı açısından mükemmellik seviyesine ulaşmak için önemli bileşenleri temsil eden çok çeşitli kritik başarı faktörlerinin değerlenmesinin bir sonucudur. Metodoloji, stratejik profil oluşturma yönteminin uygulanması ve farklı birçok yapısal ve pratik başarı faktörlerinin tanımlanması ile mevcut literatürden farklı bakış açısı geliştirmektedir. Gerçek verilere dayanan hesaplama deneyleri ile yaklaşımın nitel tarafını değerlendirecek duyarlılık analizleri çalışmaya dahil edilmiştir. Altı ana merkezin bağlantı puanları ve her faktörde elde ettikleri mükemmellik seviyeleri hesaplanmıştır. Sonuçlar, Türk Hava Yolları'nın İstanbul'daki merkezinin en büyük bağlantı değerine sahip olduğunu ve genel sonuçların literatürde sunulan sonuçlarla karşılaştırılabilir olduğunu göstermektedir. Son olarak, duyarlılık analizi, metodun nitel bileşenlere duyarlı olmadığını ve verimlilik analizi tüm merkezlerin benzer şekilde performans gösterdiğini ve etkinliklerini iyileştirmeleri gerektiğini göstermiştir.

1. INTRODUCTION

After deregulations in aviation industry, the industry has become more competitive. With the rise of the low cost carriers during 1990s, the competition in the industry significantly increased, forcing network carriers to be more efficient to stay profitable [1]. This led to the emergence of the hub-and spoke network model which provides a better utilization of resources with enhanced network coverage [2]. Network structure with a hub can serve the markets through transfer passengers as well as direct nonstop passengers. Hub connectivity is an important performance measure to evaluate hub efficiency and network coverage. Better connectivity enhances network performance by improving passenger potential and market share.

Connectivity is the accessibility of a network. Hub connectivity is the ability of a network to transfer passengers from one destination to another in the network through the hub [3]. Today, most of the world's largest airlines are operating through hub-and-spoke network and focusing on transfer passenger markets [4]. And these airlines' hubs have become major competitors for important international passenger markets. With the changing customer expectation and industry dynamics, transfer itineraries via different hubs compete with each other as well as direct itineraries. Therefore, hub connectivity measures attract many researches and airline leaders to evaluate and benchmark the competitiveness of airline hubs.

Different connectivity measures have been developed and empirical comparative analyses between airline hubs are presented in literature (these will be listed and explained in Section 2). These measures calculate weighted number of viable connections using functions considering various network properties such as number of destinations, frequency, transfer times at hub, flight times, detour, etc. The results of these researches showed that depending on the factors considered in the connectivity measure, conclusion of the analysis and ranking of airlines in the empirical results may change. With this result, selection of the set of properties considered has gained importance based on commercial and strategic objectives of the airlines since it may change the outcome of the comparative analysis as indicated in [5].

This research develops a new methodology based on a strategic management tool, competitive profiling matrix, to benchmark hub connectivity performance of selected major network carriers. Being well aware of that the set of properties included in the connectivity function may affect the competitiveness scores of the carriers, it is used as a convenience and a motivation to construct the competitive profiling method to reveal the different dimensions where the airlines' strengths and weaknesses occur. Having a qualitative side, the competitive profiling method, including expert opinions provides a good fit to measure the overall connectivity score depending on and evaluating different dimensions. Expert opinions reflect evaluations of airline specialists and align the connectivity values with the strategic and commercial objectives of airlines.

The methodology combines a wide range of critical success factors representing key components to achieve a level of excellence in terms of hub connectivity. Detour factor (fraction of travel distance to the non-stop direct travel distance), waiting time at the hub in case of transfer flights, travel time, frequency depth, physical coverage, broadness, regional coverage, revenue and passenger potential are examples of such dimensions selected as the critical success factors. The methodology evaluates and benchmarks strength and weaknesses of airline hubs and calculates an overall connectivity competitiveness score. The results will lead to strategic network improvement directives.

This research develops a unique perspective with the application of a strategic management tool to evaluate the competitiveness of hubs. In addition, this study considers the largest number of attributes altogether to calculate connectivity. There are not any studies that combines qualitative strategic management approaches forcing input of airline commercial and strategic objectives and this many attributes to construct a performance measure. Methodology is demonstrated with computational experiments as well as a sensitivity analysis to validate the results and to appraise the qualitative side of the approach.

The paper is organized as follows. Section 2 overviews the literature describing different connectivity measures. Section 3 presents the details and the development of the new connectivity measure. Section 4 describes the implementation details about the function and several computational experiments. Section 5 concludes the paper with the final remarks.

2. LITERATURE REVIEW

Various connectivity measures based on different network properties have been proposed in the literature. The scope of developed measures is in general limited to the data availability and is structured depending on the objectives of researchers. Most common network properties used in these measures are travel time, flight time, connection time, number of connections, number of stops and detour factor. In [6] the authors review connectivity measures in the previous literature. They include information about the list of network metrics used and the form of functions to calculate the connectivity scores. Two of the earlier works in the area are [7] and [8]. They describe connectivity functions based on minimum and maximum connection times which may change depending on the region of the flights. In [9], [10] and [11], the authors propose weighted connectivity measures considering both connection time and routing factor. Another study based on network properties is [12] and it is proposing a measure based on a pattern recognition algorithm searching for statistically significant patterns of incoming and outgoing flights under some minimum and maximum connection time limits. In [13], authors use the shortest path and the quickest way theories to construct connectivity measures by counting paths with minimum number of stops and minimum travel time, respectively. This study also takes the detour factor into account. Veldhius, in [14], develops Netscan connectivity function that considers travel time and non-stop direct travel time. Complementing the literature on connectivity functions, [15] introduces a practical tool that builds feasible flight connections based on connection time, detour factor, block time and a hypothetical flight time with a detour factor of one.

All of the previous literature listed so far are discussing connectivity measures based on most classical network properties. Besides network properties, depending on the objective of the researcher, different properties may also be considered in the measure. The report [16] lists some examples of such connectivity measures from literature such as York Aviation Business Connectivity Index, World Bank Air Connectivity Index [17], IATA Connectivity Index [18]. Another example is [19], the author develops a measure based on the number of flights, the number of seats per flight and the size of the destination airports. A recent study by [20] considers connection time, detour factor, perceived travel time, type of the aircraft (wide or narrow body), and frequency of the origin and destination pair. Another recent study, [5] proposes a new connectivity measure including both network properties and commercial objectives. This study in [5] considers the largest number of properties altogether until this paper. The properties considered in in [5] are waiting time at hub, detour factor, waiting time in relation to flight time, number of stops, average passenger revenue and average passenger demand.

In the process of strategy formulation and constructing a strategic plan, SWOT analysis (an analysis of external and internal factors to identify strengths, weaknesses, opportunities and threads) and competitor analysis are basic steps to be taken. The Competitive Profile Matrix (CPM) is one of the strategic management tools that compares a company with its competitors and reveals their relative strengths and weaknesses. The tool compares the company with its rivals based on some critical success factors, evaluating the company's strengths and weaknesses relative to its competitors. The success factors depend on the nature of the business and the objective of the decision makers. With CPM, decision makers can assess how to improve or maintain the sustainability and competitiveness. General description of CPM methodology with simple examples can be found in [21] and [22].

The author lists the benefits of the CPM in [21]:

• Since the same factors are used in the analysis, the comparison is more accurate,

• Matrix form makes the information and comparison more visual

• The results can lead the decision makers to decide which areas to be strengthened and what strategies to be pursued by revealing strengths and weaknesses.

In a recent study [23], author explains how CPM helps a firm to improve its competitive position and strategy formulation. The study points out that although CPM analysis may be subjective and lack robustness due to determining critical success factors and weights, the methodology can be improved by using other tools such as the Internal Factor Evaluation Matrix (IFEM), the External Factor Evaluation Matrix (EFEM), the Analytic Hierarchy Process (AHP), and the ELECTRE III. For further reading of the methodology and its extension with other methods, see [24], [25], [26], [27], [28].

This study differs from the previous connectivity literature considering a wider range of properties (eleven critical success factors in achieving higher connectivity) altogether. This study was inspired by [5] in selecting the factors considered. In addition, this study is the first in literature combining a qualitative strategic management tool which utilizes expert opinions as a reflection of airline strategies to obtain a new quantitate measure of hub connectivity.

3. COMPETITIVE PROFILE MATRIX (CPM) TO EVALUATE HUB CONNECTIVITY

The aim of this study is to develop a methodology that helps us answer the following research questions from the perspective of an airline network professional.

• How can we measure the hub connectivity by considering all the important factors affecting connectivity?

• How can we compare the hub connectivity of rival airlines?

• What are the weaknesses and strengths of these hubs with respect to each other?

• How can an airline improve its connectivity?

• What are the efficiencies of hubs in terms of achieving connectivity?

To answer the questions listed, CPM methodology is used to develop a new hub connectivity measure. The strategic management view obtained from CPM is led to a new framework for decision makers to formulate improvement strategies by identifying the performance of a particular hub with respect to its competitors. This research is a first in utilizing CPM methodology, a management tool, to obtain a connectivity measure that will also serve as a decision support tool to analyze the strength of a hub from different important dimensions.

CPM is a strategic management tool that is used to analyze the competitiveness of a company and to identify strengths and weaknesses with respect to its rivals and its current strategic position [24]. To compare rival companies, CPM methodology determines a set of critical success factors (CSF) which support or are components of a specific common objective. Then, CPM calculates the overall achievement based on the relative strengths of each company in each factor determined by the expert evaluations [23]. An example template is given in Table 1. The relative strengths of the companies are generally measured by scores from 1 to 4 which are set based on calculated quantitative values corresponding to success factors. Score 1 represents a major weakness, 2 represents a minor weakness, 3 represents a minor strength, and score 4 represents a major strength. Overall the total score of each company is equal to the weighted summation of their individual scores. Weights are presenting the relative importance of each critical success factor to the overall success for the objective. Details of the application of CPM methodology to hub connectivity are explained in the following sections.

Table 1. An example of application of CPM.

		Relative Strength of Each: 1:major weakness; 2:minor weakness; 3:minor strength; 4:major strength			
CSF	**Weight of CSF**	**Comp. 1**	**Comp. 2**	**Comp. 3**	**Comp. 4**
Factor 1	0.2	1	1	3	4
Factor 2	0.3	4	2	2	2
Factor 3	0.3	3	3	2	3
Factor 4	0.1	4	2	1	4
Factor 5	0.1	4	1	1	2
Overall Objective	Total= 1	3.1	2	2	2.9

3.1 Critical Success Factors

The main step of CPM is to determine critical success factors (CSFs). CSFs are variables representing key areas which must be performed at the highest possible level of excellence to achieve intended objectives [29] and to succeed in a particular mission. CSFs can be internal or external factors that have impact on achievement of the objectives or improvement of performance.

Eleven critical success factors are determined based on the six factors considered in the connectivity function and the special cases developed in [5]. These success factors can be classified into three categories: Network quality properties, properties defining the broadness of network and commercial objectives. All these categories are significant from an airline’s perspective to achieve competitive hub connectivity under the objectives of efficiency of resources, maximizing customer satisfaction and commercial objectives such as maximizing passenger and revenue potential. Table 2 presents the list of CSFs identified in this research. The first nine CSFs are internal factors and the last two CSFs are external factors indicating the market attributes.

Table 2. Critical success factors used to calculate hub connectivity.

Network quality properties: CSF 1. Connectivity based on waiting time at hub CSF 2. Connectivity based on detour factor CSF 3. Connectivity based on number of stops of connections CSF 4. Connectivity based on waiting time at hub in relation to flying time CSF 5. Connectivity based on number of connections
Broadness of network: CSF 6. Connectivity based on number of destinations CSF 7. Number of unique origin and destinations CSF 8. Connectivity based on long-haul: including at least one long haul flight in the connection CSF 9. Connectivity based on long-haul: Long haul to long haul flights
Commercial Dimensions: CSF 10. Connectivity based on passenger fare CSF 11. Connectivity based on passenger volume

For each CSF, connectivity of an airline hub is calculated based on a specific function. Let K be the set of all connections through the hub of an airline, n^k be the frequency for connection k (i.e., number of connections), w_{CT}^k, w_{DT}^k, w_{NS}^k, w_{FT}^k, w_{PF}^k, w_{PD}^k be piecewise linear weight functions for waiting time at hub, detour factor, number of stops of connections, waiting time at hub in relation to flying time, passenger fare, passenger demand, respectively. Let CT be the connection time and FT be the flight time for a connection. Then the following functions are used to find quantitative values for the following CSFs:

CSF 1. Connectivity based on **waiting (connection) time** at hub:

$$f_{CT} = \sum_{k \in K} w_{CT}^k \, n^k \qquad (1)$$

CSF 2. Connectivity based on **detour factor:**

$$f_{DT} = \sum_{k \in K} w_{DT}^{k} n^{k} \quad (2)$$

CSF 3. Connectivity based on **number of stops** of connections:

$$f_{NS} = \sum_{k \in K} w_{NS}^{k} n^{k} \quad (3)$$

CSF 4. Connectivity based on **waiting time** at hub **in relation to flying time:**

$$f_{FT} = \sum_{k \in K} w_{FT}^{k} n^{k} \quad (4)$$

CSF 5. Connectivity based on **number of connections:**

$$f_{NC} = \sum_{k \in K} n^{k} \quad (5)$$

CSF 10. Connectivity based on **passenger fare:**

$$f_{PF} = \sum_{k \in K} w_{PF}^{k} n^{k} \quad (6)$$

CSF 11. Connectivity based on **passenger volume:**

$$f_{PD} = \sum_{k \in K} w_{PD}^{k} n^{k} \quad (7)$$

where,

$$w_{CT}^{k} = \begin{cases} 1 & CT \le 180 \\ 0.5 & 180 < CT \le 360 \\ 0.25 & 360 < CT \le 480 \\ 0 & o.w. \end{cases} \quad \forall k \in K$$

$$w_{DT}^{k} = \begin{cases} 1 & DT \le 1.20 \\ 0.5 & 1.20 < DT \le 1.50 \\ 0.25 & 1.50 < DT \le 1.80 \\ 0 & o.w. \end{cases} \quad \forall k \in K$$

$$w_{NS}^{k} = \begin{cases} 1 & NS = 0 \ or \ 1 \\ 0.5 & NS = 2 \\ 0 & 0 \end{cases} \quad \forall k \in K$$

$$w_{FT}^{k} = \begin{cases} 1 & CT/FT \le 1.3 \\ 0.5 & 1.3 < CT/FT \le 1.5 \\ 0.25 & 1.5 < CT/FT \le 2 \\ 0 & o.w. \end{cases} \quad \forall k \in K$$

$$w_{PF}^{k} = \begin{cases} 0.25 & PF \le LF \\ 0.5 & LF < PF \le MF \\ 1 & PF > MF \end{cases} \quad \forall k \in K$$

and

$$w_{PD}^{k} = \begin{cases} 1 & PD > MD \\ 0.5 & LD < PD \le MD \\ 0.25 & PD \le LD \end{cases} \quad \forall k \in K \cdot$$

The piecewise linear weights, w_{CT}^{k}, w_{DT}^{k}, w_{NS}^{k}, w_{FT}^{k}, w_{PF}^{k}, w_{PD}^{k} are the same as the ones used in [5]. In [5], author justifies the limit values of piecewise weights based on the literature and numerical values retrieved from the market data. In functions w_{PF}^{k}, w_{PD}^{k}, LF, MF, LD and MD correspond to values used to divide market fares into three categories of low fare (LF), medium fare (MF) and high fare and market demands into three categories of low demand (LD), medium demand (MD) and high demand.

The remaining CSFs are calculated by straight forward calculations from the data of feasible connections. CSF 6 is the number of destinations for an airline, CSF 7 is the number of unique origin and destination pairs offered by an airline, CSF 8 calculates the sum of connections that have at least one long haul flight and CSF 9 calculates the sum of connections with at least two long haul flights.

Note that each CSF is individually a measure of connectivity defined by a function calculating the sum of weighted connections in the scope. For example, CSF 2 is the sum of connections weighted depending on the detour factor of each connection included; CSF 2 is not the average detour factor of the specific airline however it is the connectivity value associated with the detour factor.

3.2 Weight for Each Critical Success Factor

Each success factor has a weight in the CPM showing the relative importance of each factor to the overall achievement. Weights are determined by expert opinions. In order to do that, a survey was given to network and strategy specialists who are working for airlines considered in this study and some academics who have done connectivity research. The survey asks to rate the significance of each critical success factor in affecting the overall hub connectivity. The rates can be any integer from zero to five: zero means that the specific CSF has no effect while 5 means that the CSF has significant impact to evaluate hub connectivity. Following weights given in Table 3 are calculated based on the average values obtained from the survey of about 25 people. Summation of all weights are equal to one.

Table 3. Weights for each CSF.

CSFs	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6
Weight	0.1	0.1	0.1	0.1	0.1	0.1
CSFs	CSF7	CSF8	CSF9	CSF10	CSF11	
Weight	0.1	0.07	0.07	0.07	0.09	

4. COMPUTATIONAL RESULTS

4.1 Data Details

CPM is applied to compare the hub connectivity of six airlines at their major hubs: Turkish Airlines' (TK) Istanbul (IST) hub (IST-TK), Lufthansa's (LH) Frankfurt (FRA) hub (FRA-LH), Air France's (AF) Paris (CDG) hub (CDG-AF), British Airways' (BA) London (LHR) hub (LHR-BA), Emirates' (EK) Dubai (DXB) hub (DXB-EK) and Qatar Airways' (QR) Doha (DOH) hub (DOH-QR). (Note that, IST here refers to Istanbul Ataturk Airport which is the hub of Turkish Airlines during the period of the data used.)

All direct connections to/from these hubs and all indirect connections via the hubs operated by the selected airlines are retrieved from the OAG Analyser [30] on October 25, 2018. In this study, one of the peak summer weeks, the week starting at 15 August 2016 is used. Only indirect connections from an international destination to another international destination and direct connections to international destinations are considered in the analysis. Since these airlines are competing with each other in the international direct and transfer markets, domestic flights are not included in the study. Table 4 shows the size of the data: the number of indirect connections from hub (from one international destination to another international destination (2nd column of Table 4)), the number of direct international connections (3rd column of Table 4) and number of unique international destinations in the network (4th column of Table 4). IST-TK and FRA-LH hub have about two hundred thousand connections, other hubs are 50%-70% of those in size.

Table 4. Data size for each hub extracted from OAG (1: number of connections in the raw data with a connecting time that is less than or equal to 8 hours and a detour factor less than or equal to 1.80).

Hub Airport	# Of INT-INT Connections[1] Via Hub	# Of Direct Conn. To/From Hub	# Of INT Dest.
CDG-AF	129739	3278	138
LHR-BA	147242	4214	138
DXB- EK	122032	3805	138
FRA-LH	193222	3952	157
DOH-QR	120314	3588	150
IST-TK	203794	5081	228

4.2 CPM To Measure Hub Connectivity

This section provides the details of how to use CPM methodology to obtain a hub connectivity measure. Performance values for all critical success factors and for all airline hubs are calculated based on the equations described in Section 3.1. In order to evaluate the relative strength of airlines, for each critical success factor, performance values of airline hubs are normalized based on the airline hub with the minimum value of the associated factor. The airline with the minimum function value gets a score of 100 for the specific CSF. The normalized function values calculated using equations in Section 3.1 are given in Table 5.

Table 5. Normalized CSF values.

CSFs	AF	BA	EK	LH	QR	TK
1	106	118	100	166	108	164
2	103	117	100	153	100	173
3	112	129	100	166	104	172
4	107	122	106	145	100	171
5	107	122	102	159	100	169
6	100	100	100	114	109	165
7	103	100	105	136	128	263
8	220	238	184	222	100	196
9	250	285	202	187	106	100
10	109	127	115	141	100	165
11	118	151	108	184	100	141

Depending on the normalized values, for each CSF, each airline hub is assigned a relative strength score from 1 to 4. Score 1 represents a major weakness, 2 represents minor weakness, 3 represents minor strength, and score 4 represents major strength. In order to avoid being qualitative on assigning relative strengths to each airline for each CSF and to have consistency for all CSFs, a scale is determined to set the relative strengths. Let f_c^N be the normalized function value associated with CSF c. Then, the relative strength score, g_c is set as follows in Equation (8). The interpretation is that if an airline has only up to 20% better score than the minimum value, the strength score is set to 1, which means that it has major weakness based on the associated CSF. Similarly, an airline has the strength score of 2 (minor weakness), when it has a score which is 20% to 40% better than the minimum score in the set; it has a score of 3 (minor strength) with a 40% to 60% better score than the minimum score; and has a score of 4 (major strength) with a score greater than 60% of the minimum score.

$$g_c = \begin{cases} 1 & if\ 100 \le f_c^N \le 120, \\ 2 & if\ 120 < f_c^N \le 140, \\ 3 & if\ 140 < f_c^N \le 160, \\ 4 & otherwise. \end{cases} \quad (8)$$

Table 6 shows the results of the CPM. The relative strengths that are calculated by applying Equation (8) to normalized CSF values are presented in Table 6. Hub connectivity score for each airline hub which is the weighted summation of scores for all CSFs is shown in the last row of Table 6 in bold. IST-TK hub has the largest connectivity value, 3.70; FRA-LH has the second largest connectivity score, 3.13. Hub connectivity scores of other airlines lay in the range of 1 to 2. The results shows and compares relative strengths of hubs with respect to each other. The results are highly correlated (about 99.4%) with the total number of connections (see Table 4), which is natural for measuring hub connectivity. In fact all CSFs are connectivity functions depending on the number of connections.

Table 6. CPM: Relative strengths are calculated based on the values normalized with the minimum.

CSF	Weight	Relative Strengths (1 to 4)					
		AF	**BA**	**EK**	**LH**	**QR**	**TK**
1	0.1	1	1	1	4	1	4
2	0.1	1	1	1	3	1	4
3	0.1	1	2	1	4	1	4
4	0.1	1	2	1	3	1	4
5	0.1	1	2	1	3	1	4
6	0.1	1	1	1	1	1	4
7	0.1	1	1	1	2	2	4
8	0.07	4	4	4	4	1	4
9	0.07	4	4	4	4	1	1
10	0.07	1	2	1	3	1	4
11	0.09	1	3	1	4	1	3
Total	**1**	**17**	**23**	**17**	**35**	**12**	**40**
		Weighted Relative Strengths					
		1.42	**1.97**	**1.42**	**3.13**	**1.10**	**3.70**

4.3 CPM To Evaluate Strengths and Weaknesses

Besides calculating the overall connectivity score, the CPM methodology provides information about the weaknesses and strengths of hubs with respect to important performance metrics, in particular, aspects denoted by CSFs. From this information, the decision maker can do competitiveness analysis and derive improvement directions and strategies for an airline hub. In CPM, the information in the 3rd to 8th column in Table 6 shows the strength score of each hub based on each CSF. presents the visualization of this information. IST-TK hub is strong in all factors except it has significantly lower connectivity in terms of long haul to long haul flights (CSF 9), and has slightly lower performance in terms of connectivity based on passenger demand (CSF 11). These results are not surprising since CFS 9 can be affected by the geographical location of the hub and CSF 11 is affected by the demand volume in markets that the airline is serving. Similarly, FRA-LH hub is strong in CSF 1, CSF 3, CSF 8, CSF 9 and CSF 11; and it needs to improve connectivity in terms of CSF 2, CSF 4, CSF5, CSF 6, CSF 7, and CSF 10. Similar improvement directions can also be derived for the remaining airline hubs from the results of CPM. DOH-QR and DXB-EK got the lowest scores in almost all CFSs. This is mostly because they have lower number of connections compared to other hubs.

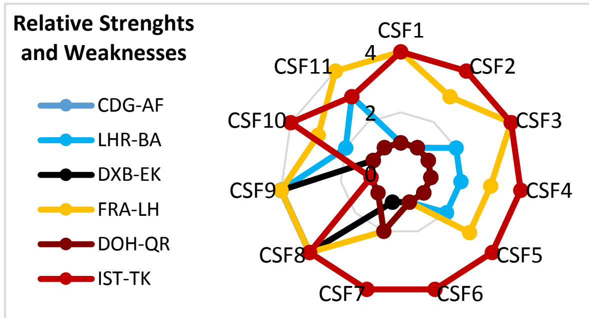

Figure 1. Visualization of strengths and weaknesses from CPM results.

4.4 Comparison of CPM Results with Literature

In this section, to validate and elaborate more on the results, the results of CPM methodology are compared with the results of revenue based connectivity measure (RBCM) developed in [5]. RBCM considers properties that are measured in CSF 1 to 4, CSF 10 and 11, and considers number of connections (CSF 5) indirectly and naturally. RBCM from the literature was chosen for the comparison with this new methodology since the intersection of the set of properties that are considered in CPM and RBCM is large. In RBCM, metrics related to these factors are multiplied with each other to get an overall weight for each connection. This magnifies the penalization of each factor. However, in CPM, the overall connectivity score is a weighted sum of other connectivity dimensions. In both CPM and RBCM, connectivity scores are directly correlated with number of connections. Figure 2 presents the results of both measures. Since the results of two measures are in a different scale, radar graph with secondary axes is used. The results of CPM are in general consistent with the previous study, RBCM. The results also confirm that the relative strength of hubs with respect to each other are also comparable in both measures. One particular difference is that IST-TK's connectivity is superior to all other hubs in CPM while in RBCM, connectivity score of FRA-LH is slightly superior to IST-TK. This is mainly due to the fact that FRA hub has more connectivity in higher demand markets compared to IST-TK hub and impact of passenger demand dimension is larger in RBCM. Passenger demand attribute is contributed to the result as a weighted sum in CPM, and this does not lower the overall connectivity superiority of IST-TK with respect to other airline hubs. In [5], it is stated that if only network properties such as waiting time, detour, etc. are considered as well as passenger fare, IST-TK hub has the best connectivity. The results of CPM confirm that IST-TK hub is very strong in terms of network properties and passenger fare. The results of other hubs in CPM are in line with the results of RBCM.

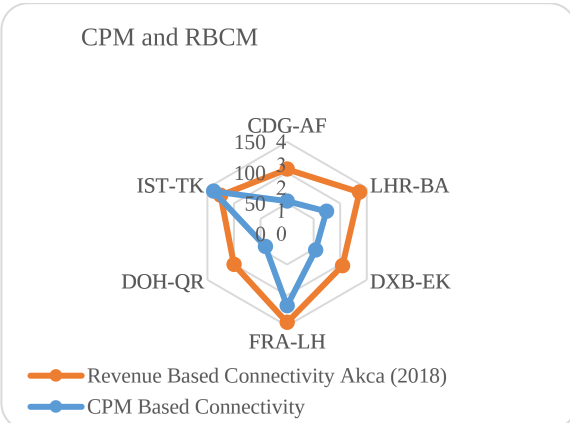

Figure 2. Connectivity based on CPM and RBCM.

4.5 Sensitivity Analysis

Application of CPM methodology produces a unique approach to measure hub connectivity and to do competitiveness analysis in terms of important components of connectivity as well as in overall connectivity. However, one downside of CPM approach is that the weights for each CSF are assigned based on expert opinion, which gives a qualitative side to the approach. In addition, even though numeric CSF values can be calculated, strength scores of 1 to 4 are assigned based on a designed scale. Therefore, in order to justify the results, a twofold sensitivity analysis is designed and applied. First, sensitivity to the weights, and second sensitivity based on the assignment of strength scores are investigated.

There are eleven weights (summation of which are equal to one), therefore a full scenario analysis investigating all possible values of all eleven weights is very difficult. For that reason, Monte Carlo Simulation methodology, a widely used approach that enables evaluation of broad range of possible scenarios by generating large number of repeated random samples is applied. For each weight, a random number between 0 and 1 is generated to obtain a set of eleven random numbers, then these eleven random numbers are transformed to a set of weights by scaling the sum of the set to 1. Samples of eleven weights with size 100 are generated and this sampling is repeated 20 times. Therefore, 2000 samples are created in total. Table 7 summarizes the results of Monte Carlo simulation including average connectivity score for each airline, sample minimum and maximum values as well as standard deviations. The results indicate that the CPM results are not very sensitive to the CSF weights. Based on the average of samples, total weighted relative strength of each airline is similar to the CPM results, i.e., IST-TK has the largest score which is more than 3.63, FRA-LH has the second largest score of 3.18, LHR-BA has the third largest score of around 2, CDG-AF and DXB-EK (with exactly same relative strength score for each CSF) have total score around 1.5 and DOH-QR has the lowest score around 1. In addition, Figure 3 displays the total connectivity score for each airline for the first 500 samples. The visual representation also supports the result that the CPM connectivity values are not sensitive to the weights, i.e., realizations for each airline appear in a similar pattern, stays in a specific range and each airline's relative position is similar. Results of each sample are investigated, in 5.6% of these samples FRA-LH gets higher score than IST-TK hub, the rankings (relative positions) of other airlines are same in all samples. FRA-LH gets higher score than IST-TK hub if CSF 9 and CSF 11 (where IST-TK has lower strength score than FRA-LH) have very large weight compared to other weights and some weights where FRA-LH has lower score than IST-TK are close to zero. Since these conditions are extreme conditions, this will not change the general conclusion that the CPM methodology results are not sensitive to the weights.

In the second part of the sensitivity analysis, sensitivity to the assignment policy (g_c given in Equation 8) for assigning strength scores to airlines is investigated. Let g_c, with 20% intervals (i.e., 0-20%, 20-40%, 40-60%, more than 60%) be the base case. Four additional scenarios are designed. Scenario details are given in Table 8. Hub connectivity results obtained in each scenario are displayed in Figure 4. In all scenarios, the ranks of airlines are aligned with each other. Therefore, it is concluded that the sensitivity of hub connectivity scores to the strength assignment policy is low. This is due to the fact that even if there is an assignment policy, there are specific functions to calculate the hub connectivity associated with each CSF and therefore, the assignment policy taking into consideration of these values is a solid and quantitative one.

Table 7. Summary statistics of Monte Carlo Simulation.

	CDG	LHR	DXB	FRA	DOH	IST
CPM Result (from Table 6)	1.42	1.97	1.42	3.13	1.1	3.7
Average of samples	1.55	2.09	1.55	3.18	1.09	3.63
Sample Std. Dev (of 2000 samples)	0.21	0.20	0.21	0.18	0.05	0.16
Min (of 2000 samples)	1.00	1.41	1.00	2.58	1.00	3.03
Max (of 2000 samples)	2.30	2.75	2.30	3.71	1.26	3.99
Sample Std. Dev (of 20 samples of averages of sample size 100) x100	2.2	1.9	2.2	1.5	0.4	1.4
Min (of 20 samples of averages of sample size 100)	1.50	2.05	1.50	3.15	1.08	3.61
Max (of 2000 samples of averages of sample size 100)	1.57	2.12	1.57	3.21	1.10	3.66

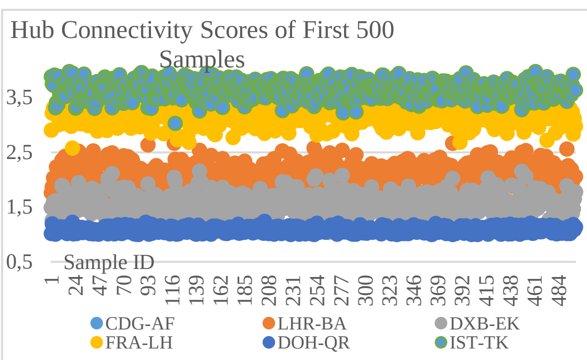

Figure 3. Hub connectivity scores of hubs for the first 500 samples.

4.6 Efficiency Based on CPM Methodology

In Section 4.2, it is stated that the results of CPM methodology are highly correlated with the total number of connections. This is reasonable since connectivity is by definition closely correlated with the number of connections. Besides the overall connectivity scores and comparative analysis of strengths and weaknesses, efficiency in this scope is also an important issue for an airline network analyst. In this section, a methodology based on CPM is developed to answer the question of how efficient network is in terms of connectivity, in other terms, how much connectivity (output) is achieved based on the available feasible connections (resources or inputs).

Table 8. Details of scenarios.

Score	Base Case - 20%	Scenario 1 - 15%	Scenario 2 - %25
1	100 <= f_c^N <=120	100 <= f_c^N <=115	100 <= f_c^N <=125
2	120 < f_c^N <=140	115 < f_c^N <=130	125 < f_c^N <=150
3	140 < f_c^N <=160	130 < f_c^N <=145	150 < f_c^N <=175
4	160 < f_c^N	145< f_c^N	175< f_c^N

Score	Scenario 3 - non uniform	Scenario 4 - non uniform based on max
1	100 <= f_c^N <=110	Values are scaled based on maximum value, % of each to maximum is calculated. Strength score is 1 if <=60%, 2 if 60% to 70%, 3 if 70% to 85% and 4 otherwise.
2	110 < f_c^N <=135	
3	135 < f_c^N <=150	
4	150< f_c^N	

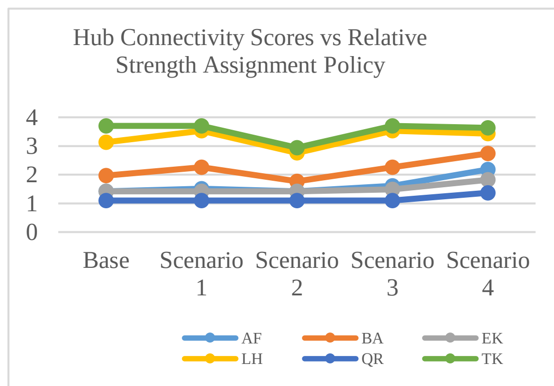

Figure 4. Sensitivity of hub connectivity scores to relative strength assignment policy.

In CPM methodology described in Section 4.2, each CSF function value is a measure of connectivity in the scope of the associated factor and depend on the number of connections (functions used are given in Section 3.1). The relative strength of each airline for each CSF is set based on the function values that are normalized with the minimum value. In order to evaluate efficiency with respect to the available connections which are indeed the resource (input) in this case, functions (of all CSFs except CSF 5 and CSF 6) are divided by the number of connections (which is the value of CSF 5). This transformation provides a degree of the percentage of achievement (for the associated CSF) with respect to the available connections. CSF 5 is simply the number of connections and CSF 6 is the number of destinations in network. It is not proper for those to get percentage over the number of connections, these are normalized with the minimum values same as the CPM described in Section 4.2. Table 9 presents the efficiency results obtained by the CPM (described in this Section).

Table 9. Application of CPM to evaluate efficiency.

CSF	Connectivity Function For CSF / Number of total connections (%) (*except 5 and 6 due to their nature)					
	AF	**BA**	**EK**	**LH**	**QR**	**TK**
1	64%	63%	64%	68%	70%	63%
2	80%	79%	82%	80%	83%	85%
3	97%	99%	92%	97%	97%	95%
4	94%	95%	99%	87%	95%	96%
5*	107	122	102	159	100	169
6*	100	100	100	114	109	165
7	8%	7%	9%	7%	11%	13%
8	28%	27%	25%	19%	14%	16%
9	1%	1%	1%	0%	0%	0%
10	80%	82%	90%	70%	79%	77%
11	75%	84%	73%	79%	68%	57%
CSF	**Relative Strengths (1 to 4)**					
	AF	**BA**	**EK**	**LH**	**QR**	**TK**
1	3	3	3	4	4	3
2	3	3	4	3	4	4
3	3	4	1	3	3	2
4	3	3	4	1	3	3
5*	1	2	1	3	1	4
6*	1	1	1	1	1	4
7	2	2	2	2	3	4
8	4	4	4	3	2	2
9	3	3	3	1	1	1
10	3	3	4	1	3	2
11	2	4	2	3	1	1
	Total Weighted Relative Strengths					
	2.48	**2.86**	**2.55**	**2.32**	**2.41**	**2.84**

Total weighted relative strengths (i.e., overall connectivity) (in Table 9) show the relative achievement of the hub with respect to its given number of connections, which can be interpreted as efficiency. All hubs performs similarly in terms of efficiency, i.e., all hubs get a score between 2 and 3. However, the ranking of hubs is very different from the overall connectivity results given in Table 6. LHR-BA and IST-TK have the largest efficiency score, FRA-LH has the lowest efficiency score and DOH-QR is very close to other airlines. The main reason that LHR-BA gets a high score in terms of efficiency even it gets a low score in overall connectivity is that it has significantly higher ratio in terms of number of stops, and passenger demand. In addition, none of the hubs achieves a score 3 or more in terms of efficiency. Therefore, they need to improve the percentage of connectivity for each CSF to the overall connectivity to improve their efficiency.

In addition, the first part of Table 9 (row 3 to row 13) provides information about the level of efficiency in terms of each CSF, showing the strengths and weaknesses as well as areas for improvement. For example, in CSF 1 which is connectivity in terms of hub waiting time, DOH-QR hub has the largest achievement with 70%; in CSF 2, which is connectivity in terms of detour factor, IST-TK hub has the highest score of 85%. Similar results can be derived for all hubs to support future strategic directives.

5. CONCLUSIONS

Hub connectivity is an important performance measure for airlines when measuring hub efficiency and network coverage to evaluate competitiveness and to decide their network improvement strategies. In this study, a new methodology based on competitive profiling matrix is developed to measure hub connectivity and to do competitive analyses. This research provides a unique perspective with the application of a strategic management tool, competitive profiling matrix method to evaluate the competitiveness of airline hubs. In addition, the methodology combines a wide range of external and internal critical success factors representing key components to achieve a level of excellence in terms of hub connectivity together, which is a first in the literature. Detour factor, waiting time during transfer, travel time, frequency depth, physical coverage and broadness properties, revenue and passenger potentials are examples of performance dimensions selected as critical success factors.

The methodology is successfully demonstrated with computational experiments with real data. The results are also compared with the results of a previous study [5] and it is concluded that the results of both measures are consistent. The main limitation of CPM approach is that the assignment of weights and strength scores requires expert opinion and a proposed policy. Therefore, the methodology has a qualitative side. In order to evaluate the effect of this qualitative side and to validate the results, a comprehensive sensitivity analysis is applied. The results prove that the measure is not sensitive to these components and the relative connectivity of hubs has not changed under the sensitivity scenarios.

Connectivity values are in definition highly correlated with the number of connections. In order to provide a comparison without the impact of the strength of hubs in terms of number of connections, this study also extends the developed methodology to evaluate the efficiency of hubs. Efficiency results show the current achievement of each hub with respect to its available connections that can be interpreted as available resources.

A limitation of the case study investigated in this research is the set of critical success factors proposed. These factors, in deed, are determined from the perspective of airline network analysts. Therefore, the factors may change depending of the objective of the researcher. However, the methodology proposed in this study offers a simple and flexible tool that can be modified, based on additional objectives for airline analysts and researchers to benchmark hub connectivity performance from different dimensions, to determine weaknesses and strengths from these different dimensions and to derive network improvement strategies for decision makers.

For future research, the CPM methodology can be improved by adding some detailed service level factors that indicate the service quality in order to extend customer satisfaction dimensions. In addition, measuring the efficiency in terms of connectivity in a more technical way is reserved for future research. Approximation of efficient frontier approaches can be utilized to calculate and benchmark the efficiency of service units with respect to resources and outputs produced.

6. REFERENCES

[1] S. A. Morrison and C. Winston, "The State of Airline Competition and Prospective Mergers," in *Competition in the Airline Industry: Hearing Before the Task Force on Competition Policy and Antitrust Laws of the Committee on the Judiciary House of Representatives*, Washington, U.S. Government Printing Office, 2004, pp. 90-96.

[2] G. N. Cook and J. Goodwin, "Airline Networks: A Comparison of Hub-and-Spoke and Point-to-Point Systems," *Journal of Aviation/Aerospace Education & Research*, Vol. 17, No. 2, pp. 51-60, 2008.

[3] International Civil Aviation Organization (ICAO), "Enhancement Of Air Transport Connectivity and Facilitation," in *Worldwide Air Transport Conference, Sixth Meeting*, 18-22 March 2013, Montreal, Canada. [Online]. Available: https://www.icao.int/Meetings/atconf6/Documents /WorkingPapers/ATConf6-wp020_en.pdf. [Accessed: Dec. 31, 2019].

[4] International Civil Aviation Organization (ICAO), "Economic Development Nov 2019: Air Transport Monthly Monitor," *Air Transport Bureau*, 2019. [Online]. Available: https://www.icao.int/sustainability/Documents/MonthlyMonitor 2019/MonthlyMonitor_November2019.pdf. [Accessed: Dec. 17, 2019].

[5] Z. Akça, "Comparative analysis with a new hub connectivity measure considering revenue and passenger demand," *Journal of Air Transport Management, 67*, pp. 34-45, 2018.

[6] G. Burghouwt and R. Redondi, "Connectivity In Air Transport Networks: An Assessment Of Models and Applications," *Journal of Transport Economics and Policy*, Vol. 47, No. 1, pp. 35-53, 2013.

[7] R. Doganis and N. Dennis, "Lessons in Hubbing," *Airline Business*, pp. 42-47, 1989.

[8] P. D. Bootsma, "Airline flight schedule development; analysis and design tools for European hinterland," PhD. dissertation, University of Twente, Utrecht, 1997.

[9] G. Burghouwt and J. d. Wit, "The Temporal Configuration of Airline Networks In Europe," *Journal Of Air Transport* Vol. 11 No. *3*, pp. 185-198, 2005.

[10] A. Danesi, "Measuring airline hub timetable co-ordination and connectivity: definition of a new," *European Transport*, vol. 34, pp. 54-74, 2006. [Online]. Available: https://core.ac.uk/download/pdf/41174582.pdf. [Accessed Dec. 31, 2019].

[11] J. F. O'Connell and O. Bueno, "A study into the hub performance Emirates, Etihad Airways and Qatar Airways and their competitive position against the major European hubbing airlines," *Journal of Air Transport Management*, Vol. 69, pp. 257-268, 2018.

[12] A. Budde, J. d. Wit and G. Burghouwt, "Borrowing From Behavioural Science: A Novel Method for the Analysis of Indirect Temporal Connectivity at

Airport Hubs," in *Proceedings of the Air Transport Research Society World Conference*, Athens, 2008.

[13] P. Malighetti, S. Paleari and R. Redondi, "Connectivity of the European Airport Network: Self-Help Hubbing And Business Implications," *Journal of Air Transport Management*, Vol. 14, No. 2, pp. 53-65, 2008.

[14] J. Veldhuis, "The Competitive Position of Airline Networks," *Journal of Air Transport Management*, Vol. 3, No. 4, pp. 181-188, 1997.

[15] A. Seredynski, F. Rothlauf and T. Grosche, "An airline connection builder using maximum connection lag with greedy parameter selection," *Journal of Air Transport Management*, Vol. 36, pp. 120-128, 2014.

[16] PWC, "Overview of Air Transport Current And Potential Air Connectivity Gaps In the CESE Region, Paper A, Final Report," *PWC*, 2014. [Online]. Available: https://ec.europa.eu/transport/sites/transport/files/modes/air/studies/doc/internal_market/2014-12-overview-of-air-transport-and-current-and-potential-air-connectivity-gaps-in-the-cese-region-paper-a.pdf. [Accessed: Dec. 31, 2019].

[17] J.-F. Arvis and B. Shepherd, "The Air Connectivity Index: Measuring Integration in the Global Air Transport Network", *The World Bank*, Policy Research Working Papers, 2011. [Online]. Available: http://documents.worldbank.org/curated/en/859151468161649899/pdf/WPS5722.pdf. [Accessed: Dec. 31, 2019].

[18] IATA, "Aviation Economic Benefits, IATA Economics Briefing No 8," *IATA*, 2007. [Online]. Available: https://www.iata.org/en/iata-repository/publications/economic-reports/aviation-economic-benefits. [Accessed: Dec. 31, 2019].

[19] B. Pearce, "Investing in Air Transport Connectivity to Boost National Productivity and Economic Growth," in *The Travel and Tourism Competitiveness Report 2007: Furthering the Process of Economic Development. Davos: World Economic Forum*, 2007.

[20] M. Logothetis and C. Miyoshi, "Network performance and competitive impact of the single hub – A case study on Turkish Airlines and Emirates," *Journal of Air Transport Management*, vol. 69, pp. 215-223, 2018.

[21] O. Jurevicius, "Strategic Management Insight, Competitive Profile Matrix," October 2013. [Online]. Available: https://www.strategicmanagementinsight.com/tools/competitive-profile-matrix-cpm.html. [Accessed: Aug. 10, 2018].

[22] H. Bhasin, "Marketing91, Competitive Profile Matrix and Analysis," April 2019. [Online]. Available: https://www.marketing91.com/competitive-profile-matrix/. [Accessed: Aug. 10, 2018].

[23] D. Bhattacharjee, M. Dey, "Competitive Profile Matrix: A Theoretical Review," *ABAC Journal*, Vol. 35, No.2, pp. 61-70, 2015.

[24] Fred R. David, Forest R. David, *Strategic management concepts and cases: A competitive advantage approach (16th ed).* Harlow: Pearson Education Limited, 2017.

[25] W. D. Bygrave and A. Zacharakis, *Entrpreneurship (2nd ed).* New Jersey: John Wily & Sons., 2011.

[26] M. Borajee and S. H. Yakchali, "Using the integrated AHP-ELECTREIII method in a competitive profile matrix," in *International Conference on Financial Management and Economics, IPEDR vol.11 (2011)*, Singapore, Singapore, 2011. [Online]. Available: https://pdfs.semanticscholar.org/1a20/ed94539f07af7871888ebf06468ca96e232c.pdf. [Accessed: Dec. 31, 2019].

[27] C. J. Capps and M. D. Glissmeyer, "Extending the competitive profile matrix using internal factor evaluation and external factor evaluation matrix concept," *The Journal of Applied Business Research*, Vol. 28, No.5, pp. 1059-1062, 2012.

[28] A. Hadighi and I. Mahdavi, "A new model for strategy formulation using mahalanobis- taguchi system and clustering algorithm," *Intelligent*

Information Management, Vol. 3, pp. 198-203, 2011.

[29] BusinessDictionay, "Critical Success Factors," *businessdictionary.com*. [Online]. Available: http://www.businessdictionary.com/definition/critical-success-factors-CSF.html. [Accessed: Aug. 10, 2018].

[30] OAG, "OAG Analyser," *analytics.oag.com.* [Online]. Available: https://analytics.oag.com/analyser-client/home. [Accessed: Oct. 25, 2018].

7. VITAE

Zeliha AKÇA received her B.Sc. degree in Industrial Engineering from Middle East Technical University in Turkey in 2002. She received her M.Sc. degree in Management Science from Lehigh University in U.S.A. in 2005. And, she received her Ph.D. degree in Industrial Engineering from Lehigh University in U.S.A. in 2009. Her Ph.D. studies were in the area of large scale optimization algorithms on integrated location, routing and scheduling problems. She is currently working at Turkish Airlines as a senior engineer and she has been building her experiences on strategic management and operations research applications in airline business.