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EVALUATING CONNECTIVITY FOR HUB AND SPOKE NETWORKS

by

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**EVALUATING CONNECTIVITY
FOR HUB AND SPOKE NETWORKS**

by

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ABSTRACT

This thesis reviews and compares 5 different methods to measure and evaluate connectivity of hub and spoke networks, presents applications of these methods using real life networks and proposes a new method to measure connectivity. 3 case studies are presented using 5 methods from the literature which are Doganis and Dennis, Bootsma, Weighted, Danesi and Netscan connectivity. The first case compares connectivity of Turkish Airlines in İstanbul hub with other major airlines in European hubs. The second case compares connectivity of Turkish Airlines' summer 2012 and summer 2011 schedules which have different wave designs in order to evaluate the effect of changing the wave structure. Third case designs and evaluates a new weighted connectivity measure that also considers transfer passenger ratio and network contribution in terms of revenue.

Keywords: Airline network, hub and spoke, network performance, connectivity

BESLE VE DAĞIT NETWORK YAPISINDA BAĞLANTI DEĞERLENDİRME

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ÖZ

Bu çalışma, beş farklı bağlantı değerlendirme modelini besle ve dağıtım ağ yapılarını ölçmek ve değerlendirmek üzere, bu modelleri gerçek hayat ağ modellerine uygular ve ağ yapısını ölçmeye yönelik yeni bir metod önerir. 3 vaka analizi; Doganis ve Dennis, Bootsma, Weighted, Danesi ve Netscan bağlantı modelleri kullanılarak sunulmuştur. Birinci vaka, ana besleme noktası İstanbul olan Türk Hava Yolları'nın bağlantı yapısını besleme noktaları beş farklı Avrupa şehri olan beş büyük havayolunun ağ yapıları ile karşılaştırır. İkinci vaka analizinde Türk Hava Yolları'nın farklı dalga tasarımına sahip olan yaz 2011 ve yaz 2012 tarife dalga yapısındaki değişimin bağlantı gelişimine etkisi değerlendirilir. Üçüncü vaka analizinde, transfer yolcu sayısı ve gelir bazında bağlantı katkısı ağırlıklandırılarak tanımlanan yeni bağlantı fonksiyonu ile literatüre katkıda bulunur.

Anahtar Kelimeler: Havacılıkta network, besle-dağıtım, network performansı, bağlantı kalitesi

To my lovely husband,

for his endless love, support and encouragement

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION

AA	America
AF	Middle and South Africa
AMS	Amsterdam
ME	Middle-East
CDG	Paris
CIS	Common Wealth of Independent States
DOM	Domestic within Türkiye
FCO	Rome
FE	Far East
FRA	Frankfurt
HS	Hub and Spoke
IATA	The International Air Transport Association
IST	İstanbul
KLM	Koninklijke Luchtvaart Maatschappij N.V. (Royal Aviation Company), the flag carrier airline of the Netherlands
MaxCT	Maximum Connection Time
Mct	Minimum Connection Time
ME	Middle East
MUC	Munich
NAF	North Africa
SA	South Asia
SAS	Statistical Analysis System software provided by SAS Institute Inc.
SPA	Special Pro-rate Agreements
PP	Point to Point
TK	Turkish Airlines (*IATA code)

CHAPTER 1

INTRODUCTION

Aviation is a large and growing industry while it is a driver for economic growth of countries, flow of world trade, international investments, intercontinental tourism. So there are a lot of market players that makes the competition unavoidable and forces airlines to become more efficient.

There exist three different strategies over air-network system point-to-point (PP), hub-and-spoke (HS) or multi-hub. Hub-and-spoke networks enable carriers to supply transport services to many combinations of origins and destinations at high frequencies. The growth of hub-and-spoke operations has changed the structure of competition among airlines and airports. Airlines now have to compete in both ways. One is direct service; other is indirectly service via a hub. To achieve being the most preferred, airlines have to identify their network performance and hub competitive position.

An HS network design focuses on the connectivity within hubs which is to be implemented by designing landing and take-off time of the flights. This design determines the outbound and inbound flights connectivity. The wave, structured by the time of outbound and inbound flights, brings on the peak times in the hubs and additionally possible delays, including missing connections (Alderrighia et al., 2005).

The disadvantage of the system is the transfer time that means, in other words, waiting time. To reduce waiting time, high frequency is an option to give more chance the passenger to catch a flight. While increasing frequency helps to reduce waiting time at airports, but the more important point is to coordinate departure and arrival times of

flights on minimal connecting times (Dennis, 1998). This makes seriously important to measure the network performance.

Air industry has put several models to measure network performance. We will study Doganis & Dennis, Bootsma, Weighted, Danesi and Netscan connectivity models to measure hub connectivity and airport accessibility. Each model considers both passenger accessibility and hub centrality. Models evaluate the performance in terms of frequency, connection times and number of connections under cut-point conditions and then derived connections are assumed as “viable” connections. Additionally, after determining the viable connections, the proposed function measures the hub connectivity.

In second chapter, aviation industry is introduced briefly. The importance of network design phase is emphasized among phases of network management and then, common network system strategies are explained and hub & spoke system is highlighted. Additionally, competition types of airlines among network types are defined. At last, some necessary aviation terminologies are explained.

In third chapter, a literature review is given on following lead of Redondi and Burghouwt, 2010 working paper. Generally, the literature for network performance is divided into two groups according to their methodologies' complexity. Low and medium complexity methods called Doganis & Dennis, Bootsma, Weighted, Danesi and Netscan connectivity models belonging to respectively Doganis & Dennis, Bootsma, Matsumoto, Danesi and Burghouwt are explained.

In the last chapter, the problem is defined and the three cases are introduced. Derived data and the evaluation methods according their evaluation function are clarified. In respect of first case, Turkish Airlines (TK) network performance is compared with other competitors' performances at European Hubs according to the models Doganis & Dennis, Bootsma, Weighted, Danesi connectivity. In the second case, the improvement of TK's Network Performance is measured and evaluated for two schedule designs using different wave structure; summer 2011 plan and summer 2012 plan. At last, in the third case, the current available methods and designing a new weighted connectivity function that includes transfer passenger ratio and network contribution affects is extended. The results are discussed among the measurement of network performance.

The analysis presented in this study may be helpful for airports or airlines in identifying their network performance and competitive position in relation to competing airports or airlines.

CHAPTER 2

NETWORK IN AVIATION

In this chapter, aviation industry is introduced briefly. The importance of network design phase is emphasized among phases of network management and then, common network system strategies are explained. Hub and spoke (HS) system is highlighted. Additionally, competition types of airlines among network types are defined. At last, some necessary aviation terminologies are explained.

2.1 NETWORK MANAGEMENT PHASES

Despite an endless number of variations, network management can be divided into four major phases. First phase is a long term perspective that network strategy should be determined. Taking market development and completion into consideration for external market forces and internal capabilities such as financial and air political context can be constantly weighed. Today, the process is reversed by providing the planned evolution of assets (aircraft and infrastructure capacity) as strategic input to network planning. Second phase is a medium-term perspective called network design, also called tactical planning. The phase basically consists of two steps after determining network system strategy; connectivity criteria design and bank structure design. These steps are aligned to meet the product and production requirements of next season's plan. The third phase is to strengthen your network by alliances. Codeshares and special pro-rate agreements (SPA) are common agreements signed between airlines to share the same products on certain flights. Network planning phase is the short-term and ongoing perspective phase comprised of connectivity optimization, crew rotation planning, fleet maintenance, spare capacity, punctuality optimization and baggage irregularity.

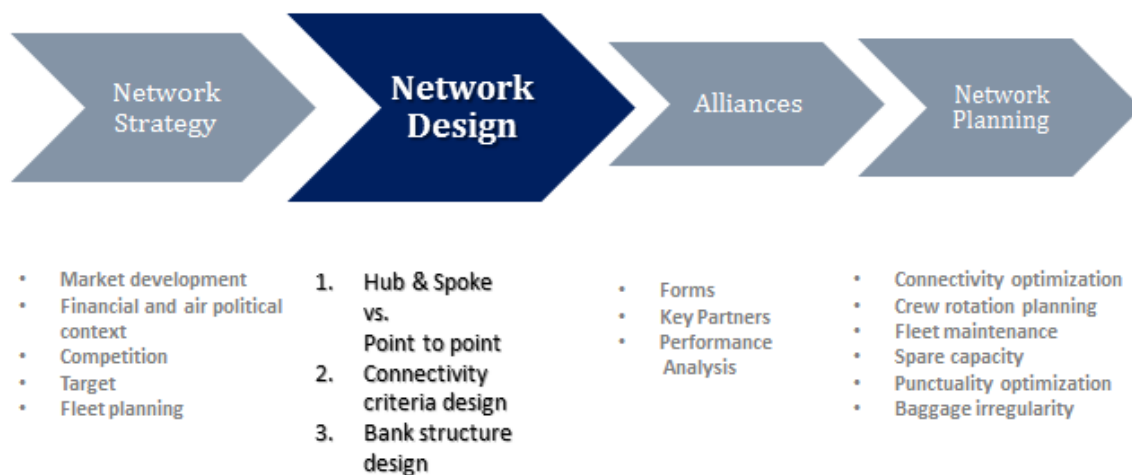


Figure 2.1 Network Management Phases (Cento, 2009).

2.2 NETWORK SYSTEM STRATEGIES

The network is a key strategic factor of airlines, as it is the main driver for generating revenue and costs as well as a source of competitive strength or weakness. The network strategy to be an integral part of the airline strategy and the network structure to be a function of demand side externalities and uncertainty, as well as supply-side network economics are considered by Gillen (2005). Since network configuration is not just a cost issue, a network strategy can contribute revenue advantages as well. The network structure ranges from fully-connected or point-to-point (PP) to hub-and-spoke (HS) to alliance (fully-contracted), or to a mix of these strategies. In that point, we basically divide network system strategies that carriers play, into three groups; point-to-point (PP), hub-and-spoke (HS), or multi-hub (MH).

2.2.1 Point-to-Point (PP)

When traffic flows are temporally and spatially dispersed, point to point network structure will be preferred. The network is developed from one or a few airports, called 'bases', from which the carrier starts operating routes to the main destinations. No connections are provided. They are directly connected.

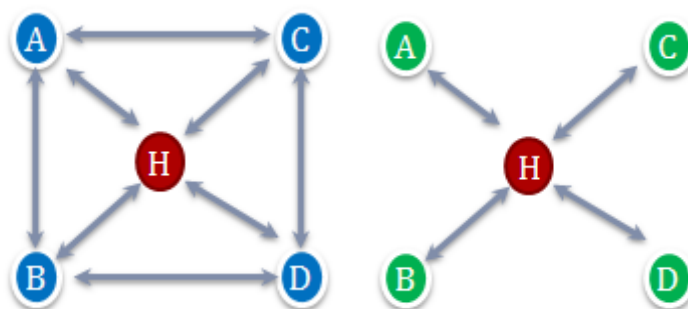


Figure 2.2 Point to Point and Hub & Spoke (Goedeking, 2010).

2.2.2 Hub and Spoke (HS)

Hub and spoke is a network where all passengers fly to a hub and then catch another flight to their final destinations (Lederer and Nambimadam, 1998). When there is a high concentration level of air traffic in space and time, hub and spoke network model is preferable. Hub and spoke network structures allow airlines to serve many origin and destinations markets with fewer flight departures, requiring fewer aircraft generating fewer available seat kilometer (ASK) at lower total operating costs than in a complete point-to-point route network (Belobaba et al., 2009).

Table 2.1 Number of Routes for PP and HS.

	Point to Point	Hub and Spoke
number of directional ROUTES	$n \times (n-1)$	$2 \times (n-1)$
number of nondirectional ROUTES	$n \times (n-1)/2$	$(n-1)$

An HS network design focuses on the connectivity within hubs which is to be implemented by designing landing and take-off time of the flights. The disadvantage of the system is the transfer time. To reduce waiting time, high frequency is an option to

give more chance the passenger to catch a flight. While increasing frequency helps to reduce waiting time at airports, but the more important point is to coordinate departure and arrival times of flights on minimal connecting times (Dennis, 1998). On the other hand, the advantage of the system is to be able to give you the chance to offer product varieties to supply demand for different origin and destinations. HS provides the multiplicative benefits in terms of the number of effective connection.

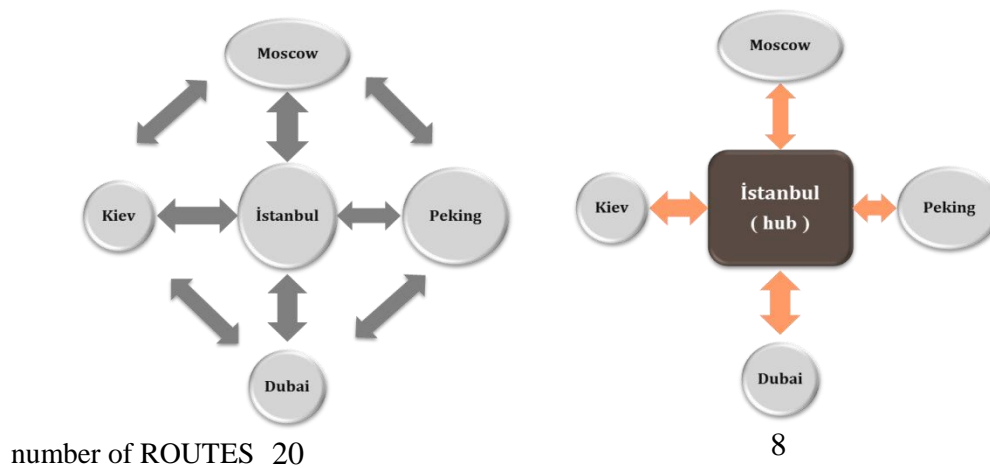


Figure 2.3 Examples for PP and HS.

The number of flights needed for each strategy is given in Figure 2.4. The gap between PP and HS strategy increases exponentially related to the number of nodes.

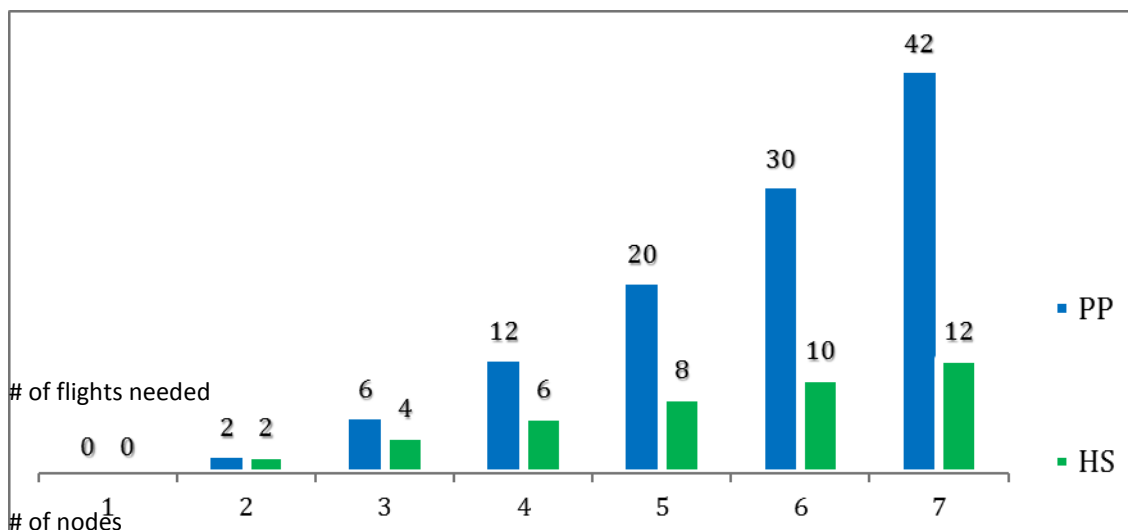


Figure 2.4 Number of Flights Needed for PP and HS (Goedeking, 2010).

2.2.3 Multi-Hub

Airlines need multiple hubs to increase spatial coverage and serve thin markets. Multi-hub design is mix of above strategies.

2.3 AIRLINE NETWORK COMPETITION

Airlines can compete in four basic ways via their networks. These four ways are presented in Figure 2.5.

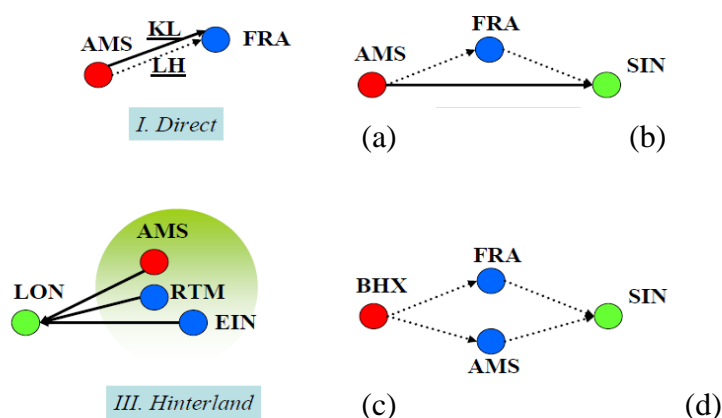


Figure 2.5 Four Types of Airline Network Competition (Burghouwt et al., 2008)
 (a) Direct (b) Direct/hub (c) Hinterland (d) Hub/hub.

2.3.1 Direct Competition

When airlines A and B are competing head to head, as given an example in Figure 2.5, on the city-pair market Amsterdam-Frankfurt, this kind of competition is called direct competition. Ticket price, flight frequency and loyalty will be the players in the passenger choice behavior.

2.3.2 Direct/Hub Competition

On the large long-haul city-pair markets, both direct connections and indirect connections via a transfer hub could exist. This kind of competition is called direct/hub competition. As pictured in Figure 2.5, the market between Amsterdam and Singapore is directly served by KLM and Singapore Airlines. On the other hand, indirectly alternative, via Frankfurt with Lufthansa also exists. For passenger choice, additionally in-flight time and transfer time are main players. If the transfer time and flying time of an indirect connection become longer, the probability of a passenger choice becomes smaller. In reality we see that, when a direct connection is available, passengers show a huge tendency to choose the airline(s) that offers a direct connection, leaving the indirect connect a relatively small market share (Matsumoto et al.).

2.3.3 Hinterland Competition

When airlines A and B are serving for the same city-pair market, but from different airports for approximately the same catchment area, this kind of competition will be called Hinterland competition. For example, airline A and B may compete on the city-pair market between the Randstad metropolitan area to London as pictured in Figure 2.5. For the passenger choice, ticket price, flight frequency, customer loyalty, additionally schedules of the products are players.

2.3.4 Hub/Hub Competition

When no direct connection is available for the market pairs, various airlines/alliances may compete via their hubs for transfer passengers. On the other hand, the direct connection is then likely to get the lion's share of the total origin-destination market (Burghouwt et al., 2008).

2.4 NETWORK CONNECTIVITY

According to Matsumoto et al., there are four types of network connectivity described in Figure 2.6.

- (a) Direct Connectivity: flights between A and B without a hub transfer.
- (b) Indirect Connectivity: flights from A to B, but with a transfer at hub X.
- (c) Onward Connectivity: connections via (with a transfer at) hub B between origin A and all destinations beyond hub B.
- (d) Hub Connectivity: connections via (with a transfer at) hub A between origin C and destination B.

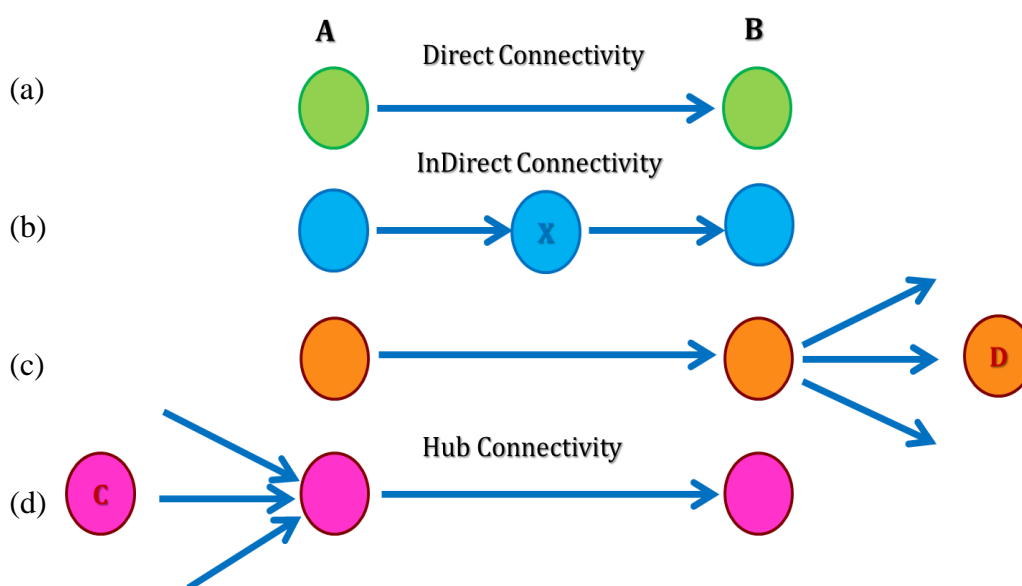


Figure 2.6 Network Connectivity (Matsumoto et al.) (a) Direct connectivity (b) Indirect connectivity (c) Onward connectivity (d) Hub connectivity.

For indirect connectivity, it becomes important to measure the connectivity because of the competition in the sector and also by the way of service quality. The number of direct and indirect connections for consumers between A and B is important by the way of hub connectivity issue for measuring the competitive position of airline hubs.

2.5 BANK STRUCTURE DESIGN: WAVE STRUCTURE

Wave structure is a display that consists of arrival flights on inbound bank and departure flights on outbound bank with timing. It is mostly a compressed time table of only one day.

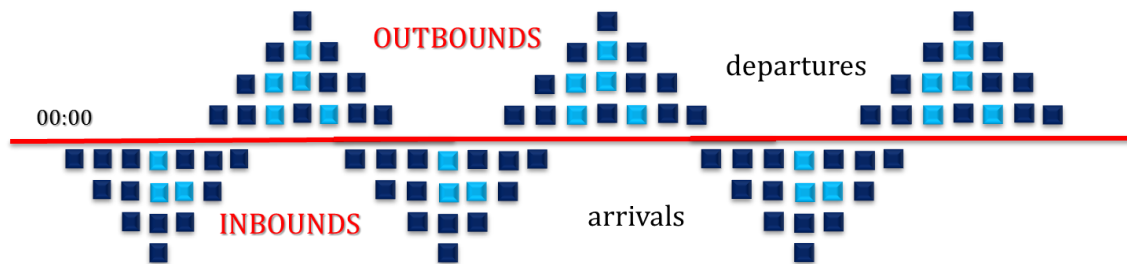


Figure 2.7 Network Structure.

Wave design determines the outbound and inbound flights connectivity. The wave, structured by the time of outbound and inbound flights, brings on the peak times in the hubs and additionally possible delays, including missing connection (Alderrighia et al., 2005). As no airport has unlimited peak capacity, an airline adding flights to a hub has two principal options (Dennis, 2001). Firstly, it can add the flights to the edge of existing waves; secondly, it can develop new waves.

After 1970, airlines have started to design their networks over wave structural design.

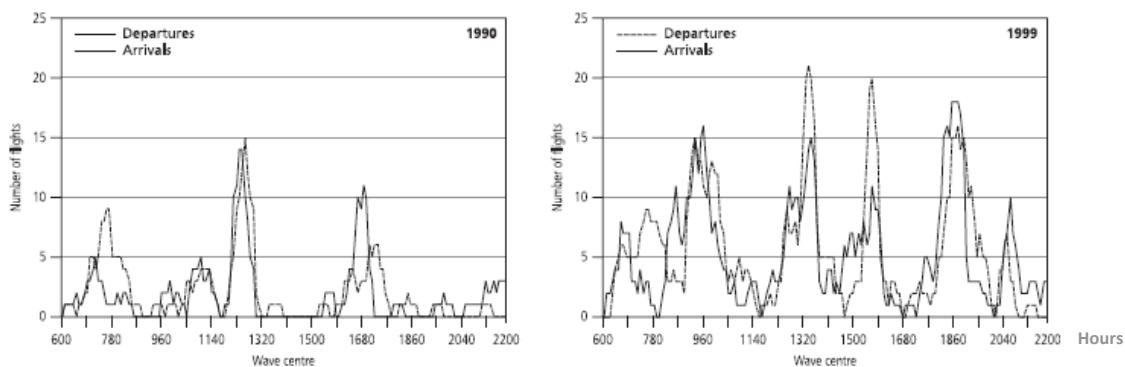


Figure 2.8 Wave system structure of KLM at Amsterdam, 1990 (left) and 1999 (right) (Burghouwt and de Wit, 2005).

In Europe, by the time, big players have added new waves to their bank structural design between 1990 and 1999 to increase their competitive advantage. In Figure 2.8, the general wave structures of KLM for the years 1990 and 1999 are given at Amsterdam. The number of total flights reaches at 15 as maximum flight number in 1990. Moreover, this number is more than 20 in 1999. On the other hand, number of waves of a daily schedule of KLM is 6, since the waves outstand as 3. Figure 2.9 shows another developing period of wave structure in Europe. In 1990, the maximum number of flights of a wave is not more than 5. On the other hand, number of flights reaches more than 10 of a wave in 1999. The number of waves of a daily schedule of the airline is 3, since the waves in 1990 do not outstand.

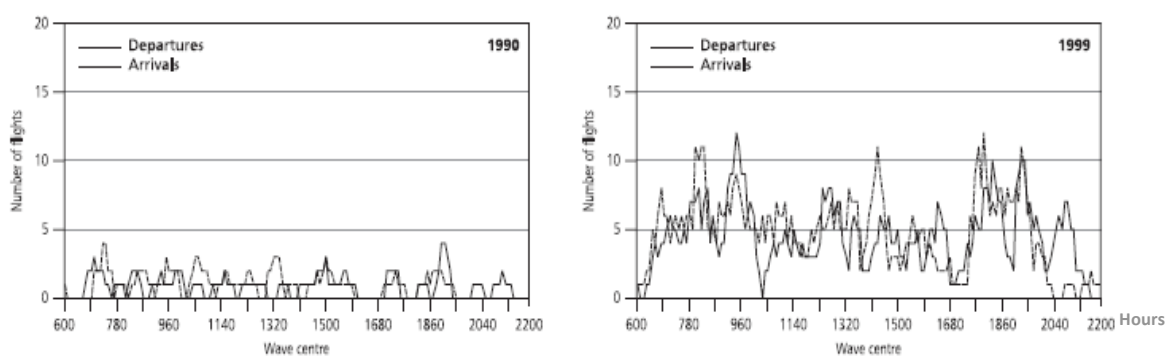


Figure 2.9 Wave system structure of British Airways at London Gatwick, 1990 (left) and 1999 (right) (Burghouwt and de Wit, 2005).

Airline Delta is one of the examples of 2000s that has reverted flat hub structure to a deep wave pattern where the number of flights reaches 60 (see Figure 2.10).

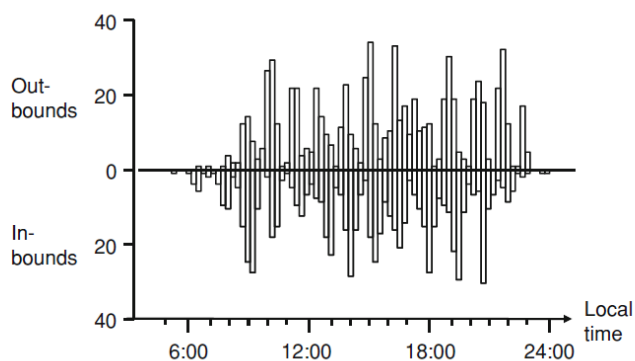


Figure 2.10 Wave Structure of Delta at Atlanta, 2005 (Goedeking, 2010).

After 2000, airlines have deepened their wave by adding new flights to their existed waves. In Figure 2.11, wave structures of winter schedules of KLM before 2009-2010 winter and 2009-2010 winter schedules are presented. The figure shows the increase of number of flights for the each wave of the structure.

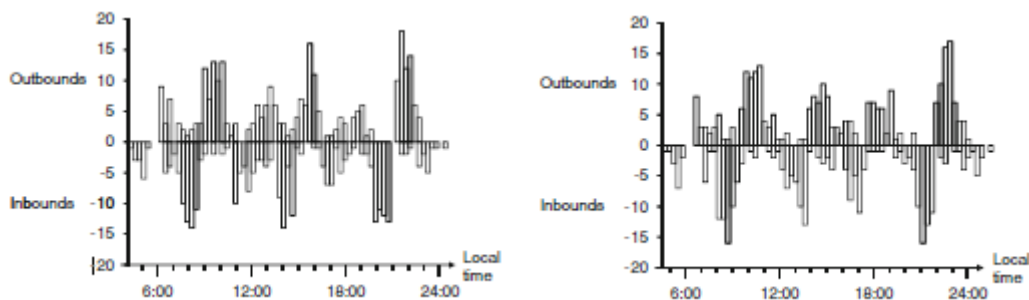


Figure 2.11 Wave Structure of KLM at Amsterdam before 2009-2010 winter (left), 2009-2010 winter (right), 2005 (Goedeking, 2010).

2.6 AIRLINE TERMINOLOGY AND DEFINITIONS FOR NETWORK PERFORMANCE

In the airline industry, there exist several common measures of airline network performance. At this point, we introduce some measures and their definitions.

Non-stop Market: It is indicated with one flight number as it exist only one leg of flight where leg is called one flight from origin to destination.

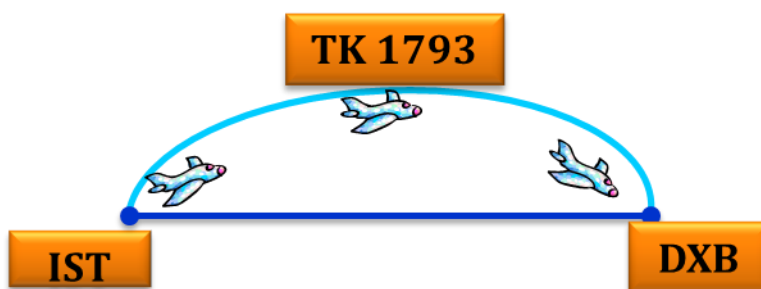


Figure 2.12 Non-Stop Market.

Direct/ Through Market: It is indicated with one flight number where exists at least two legs of flights.

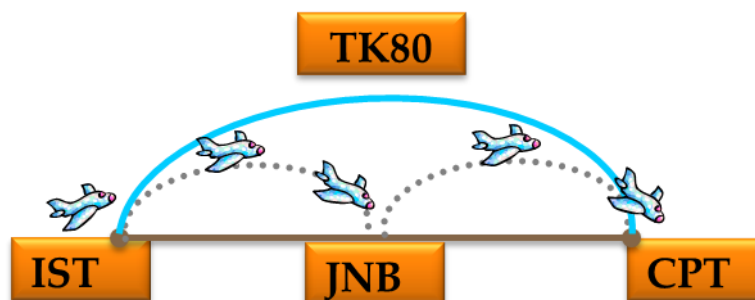


Figure 2.13 Direct/Through Market.

Connection Markets: It is indicated with more than one flight number where exists at least one stop and at least two flights legs.

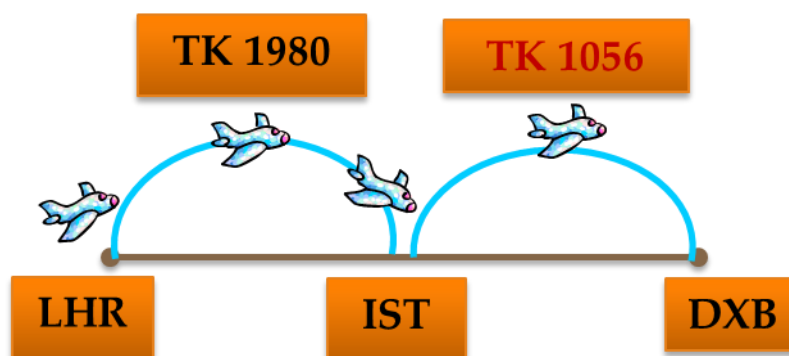


Figure 2.14 Connection Market.

Load Factor: Load factor refers to the ratio of traffic to airline output, representing the proportion of airline output that is sold or consumed (Belobaba et al., 2009). For a single flight leg, in other words for a non-stop operation, the load factor can simply be defined as the number of passengers divided by the number of seats on the flight.

Minimum connecting time (MCT): A connection must occur within the minimum connection time, The duration depends on the connection areas whether the connections are for domestic to international, international-to-domestic, domestic-to-domestic, or international-to-international connections. Since connections with at least one international segment usually require customs procedures, they typically demand a longer MCT than a connection between two short-haul domestic flights (Goedeking, 2010).

Maximum Connecting Time (MaxCT): In most of the literature, the number of connections is defined by a fixed time window called “maximum connecting time”. The idea behind maximum connection time is to determine meaningful connections between MCT and MaxCT. While Doganis and Dennis (1989) suggests a fixed maximum connection time of 90 minutes for all connections, Bootsma (1997) proposes 180 minutes for connections of continental flights, 300 minutes if one intercontinental

flight exists, and 720 minutes for connections of intercontinental flights. Danesi (2006) considers a set of values ranging from 90 to 180 minutes.

Detour: The ratio of the total of the distances of the inbound and outbound legs, over the distance between the origin of inbound leg and the destination of outbound leg is defined as detour. It is also called as routing factor.

CHAPTER 3

LITERATURE REVIEW

In this chapter, a literature review is given on following lead of Redondi and Burghouwt (2010) working paper. Generally, the literature for network performance is divided into two groups according to their methodologies' complexity. In this study low and medium complexity methods belonging to Bootsma, Danesi, Matsumoto, Burghouwt and Doganis are explained.

Weighted connectivity is used as a measure in Burghouwt, G. and J. de Wit (2005) taking into consideration minimum connecting time (MCT) of 60 minutes, maximum connecting time (MaxCT) of 180 minutes for EU connections, MaxCT of 720 minutes for intercontinental connections and maximum routing factor of 1.4 based on flight times as cut-point conditions.

The earlier study belongs to Veldhuis (1997) used as measures hub connectivity and airport accessibility and assumed MCT 60 minutes for all connections. The other study in 1997 belongs to Bootsma called Bootsma connectivity (1997). MCT of 60 minutes for all connections, MaxCT of 180 minutes for European (EU) connections; MaxCT of 300 minutes for connections from/to EU to/from intercontinental airports, MaxCT of 720 minutes for connections from and to intercontinental airports.

The study called Danesi connectivity (2006), assumes MCT of 60' for all connections, MaxCT of 120' for European connections, MaxCT of 180 minutes for all other connections. The study weighted the connections according to routing factor in terms of direct distance and flight's distance.

Table 3.1 Connectivity Measures of Low and Medium Complexity (Burghouwt and Redondi, 2013).

MODEL	SHORT DEFINITION	MAIN REFERENCES
Hub potential	Incoming & outgoing frequency	Dennis (1998)
'Doganis and Dennis' connectivity	Number of connections. Indirect connections meet conditions of minimum and maximum connecting time and routing factor.	Dennis and Doganis (1989); Dennis (1994a, 1994b)
'Bootsma' connectivity	Number of connections. Indirect connections meet conditions of minimum and maximum connecting time and are classified as 'excellent', 'good', or 'poor'.	Bootsma (1997)
WNX (Weighted Number of Connections)	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time.	Burghouwt & de Wit (2004); Burghouwt (2007)
Netscan connectivity units	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time relative to theoretical direct flight.	Veldhuis (1997); Burghouwt and Veldhuis (2006); Veldhuis and Kroes (2002); Matsumoto et al.(2008)
Danesi connectivity	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time.	Danesi (2006)

Doganis and Dennis connectivity (1989), measured MCT of 60 minutes for all connections and MaxCT of 90 minutes for all connections and then evaluated each viable connection.

Budde et al. (2008) used number of connections patterns as a measure with the cut points, MCT of 60 minutes for all connections. The patterns must be recognized as a statistically significant pattern.

Guimerà et al. (2005) studies hub connectivity and measured shortest path length. The connection must lie on the shortest path, in terms of number of steps, from origin to destination and weighted for every viable origin and destination connection.

Table 3.2 Connectivity Measures of High Complexity (Burghouwt and Redondi, 2013).

MODEL	SHORT DEFINITON	MAIN REFERENCES
Shortest path length centrality	Number of connections lying on O&D shortest paths. The shortest path is the path involving the minimum number of steps from O to D.	Shaw (1993); Shaw and Ivy(1994); Cronrath et al. (2008); Malighetti et al. (2008)
Shortest path length accessibility	Average number of steps to reach any other airport in the network.	Shaw (1993); Shaw and Ivy(1994); Cronrath et al. (2008); Malighetti et al. (2008)
Quickest path length centrality	Number of connections lying on O&D quickest paths. The quickest path is involving the lower travel time from O to D.	Malighetti et al. (2008); Paleari et al. (2010)
Quickest path length accessibility	Average travel time to reach any other airport in the network.	Malighetti et al. (2008); Paleari et al. (2010)
Gross vertex connectivity	Sum of all possible paths with three or fewer flight segments, weighted by a scalar value.	Ivy (1993); Ivy et al. (1995)
Number of connection patterns	Number of statistically significant patterns of incoming and outgoing flights.	Budde et al. (2008)

The other hub connectivity measure is called Quickest Path Length (Malighetti et al., 2008). The cut-point conditions are MCT of 60 minutes for all connections, maximum routing factor of 1.25 based on distances. The connection, viable origin to destination, must lie on the quickest path, in terms of travel time.

3.1 THE GENERAL PROCEDURE

3.1.1 Hub Connectivity Models_Centrality (Redondi and Burghouwt, 2010, 2013)

Since all measures, also measures presented in study, of hub connectivity have the same underlying principles, the measures can be presented as a two-step procedure. The hub connectivity measure of the intermediate airport is shown in Figure 2.

Step 1: Identify the connections from origin airport k to the destination airport j passing through airport i that meet some defined conditions depending on the measure. Those conditions are called as “cut-point” conditions and the resulting connections “viable” connections in the study of Redondi and Burghouwt (2010, 2013).

Step 2: Apply the following expression defined in Eq.(3.1)

$$\text{Hub connectivity measure} = \sum_1^n f(c_{j,i,k}) \quad (3.1)$$

where n is the number of viable connections and $f(c_{j-i-k})$ is a function of the characteristics of the viable connection $j-i-k$ that we call weighting function that related to the measure applied.

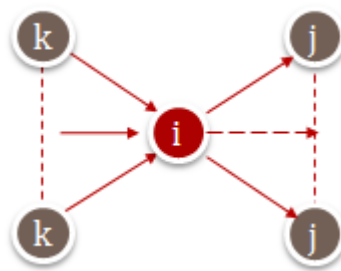


Figure 3.1 Hub Connectivity (Redondi and Burghouwt, 2010).

3.1.2 Accessibility Models (Redondi and Burghouwt, 2010, 2013)

Measures of accessibility models presented in the study have the same underlying principles. The measures can be presented as a two-step procedure. The accessibility measure of an airport i is presented in Figure 3.2.

Step 1: Identify in any airport j , directly connected to airport i , all the connections starting from origin airport i and going onwards to destination airport k that meet some defined conditions that depends on measure. Those conditions are called “cut-point”

conditions and the resulting connections “viable” connections in the study of Burghouwt and Redondi (2010, 2013).

Step 2: Apply the following expression defined in Eq. (3.2)

$$\text{Accessibility measure} = d + \sum_{j=1}^m \cdot \sum_{1}^{n_j} f(c_{i,j,k}) \quad (3.2)$$

where the first term d refers the direct connectivity while it is measured as the number of flights from origin airport i . The second term denotes the indirect connectivity or onward 2-step connectivity, where m is the number of airports with incoming flights from origin airport i , and n_j is the number of viable connections identified in the airport j ; $f(c_{i,j,k})$ is a function of the characteristics of the viable connection i - j - k that is called weighting function that differs to the measure applied.

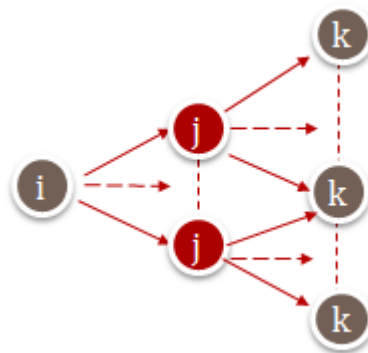


Figure 3.2 Airport Accessibility (Redondi and Burghouwt, 2010).

3.2 MODELS IN LITERATURE

3.2.1 Doganis and Dennis Connectivity

A number of connectivity measures include a minimum and maximum transfer time. This measure is one of the basic models to measure hub connectivity.

Table 3.3 Doganis and Dennis Connectivity (Redondi and Burghouwt, 2010).

Measure	Doganis and Dennis connectivity	
Main reference	Doganis and Dennis (1989)	
Applications	Hub connectivity and airport accessibility	
Cut-point conditions	<ul style="list-style-type: none"> - minimum connecting time (MCT) of 60' for all connections - maximum connecting time (MaxCT) of 90' for all connections 	
Weighting function for every viable connection	f=1	
Software	Microsoft Access	Low complexity

3.2.2 Bootsma Connectivity

The model classifies the connections as ‘excellent’, ‘good’ or ‘poor’ in case of meeting the conditions of minimum and maximum connecting time stated below.

Table 3.4 Bootsma Connectivity (Redondi and Burghouwt, 2010).

Measure	Bootsma connectivity	
Main reference	Bootsma (1997)	
Applications	Hub connectivity and airport accessibility	
Cut-point conditions	<ul style="list-style-type: none"> - minimum connecting time (MCT) of 60' for all connections - maximum connecting time (MaxCT) of 180' for EU connections - maximum connecting time (MaxCT) of 300' for connections from (to) EU to (from) intercontinental airports - maximum connecting time (MaxCT) of 720' for connections from and to intercontinental airports 	
Weighting function for every viable connection	f=1	
Software	Microsoft Access	Low complexity

3.2.3 Weighted Connectivity

Number of direct and indirect connections is weighted by their quality in terms of transfer and detour time. The model states own routing and transfer index according minimum and maximum connection times classified according to connection areas.

Table 3.5 Weighted Connectivity (Redondi and Burghouwt, 2010).

Measure	Weighted connectivity	
Main reference	Burghouwt, G. and J. de Wit (2005)	
Applications	Hub connectivity and airport accessibility	
Cut-point conditions	<ul style="list-style-type: none"> - minimum connecting time (MCT) of 60' for all connections - maximum connecting time (MaxCT) of 180' for EU connections - maximum connecting time (MaxCT) of 720' for intercontinental connections - maximum routing factor (R) of 1.4 based on flight times 	
Weighting function for every viable connection	$f = WI = \frac{2.4 * TI + RI}{3.4} ; \quad WI \text{ weighted indirect connection};$ $TI = 1 - \frac{1}{MaxCT - MCT} ; \quad TI \text{ transfer index};$ <p>T: connection transfer time; MaxCT maximum connecting time for the connection; MCT: minimum connecting time for the connection;</p> $RI = 1 - (2 * \frac{R}{2} - 2 * \frac{1}{2}); \quad RI \text{ routing index};$ <p style="text-align: center;">R routing factor;</p> $R = IDT / DTT$ <p style="text-align: center;">IDT actual in-flight time; DTT estimated in-flight time of the direct connection based on the great circle distance</p>	
Software	Microsoft Access	Medium complexity

3.2.4 Danesi Connectivity

Numbers of direct and indirect connections are weighted by their quality in terms of transfer and detour time. Detour index is assumed as maximum 1.5 .

Table 3.6 Danesi Connectivity (Redondi and Burghouwt, 2010).

Measure	Danesi Connectivity	
Main reference	Danesi (2006)	
Applications	Hub connectivity and airport accessibility	
Cut-point conditions	<ul style="list-style-type: none"> - minimum connecting time (MCT) of 60' for all connections - maximum connecting time (MaxCT) of 120' for EU connections - maximum connecting time (MaxCT) of 180' for all other connections 	
Weighting function for every viable connection	$f = \tau * \delta$; τ : connection time weight; δ : routing factor weight; $\tau = \begin{cases} \text{if } CT_{BU} < 90' . \text{or } CT_{INT} < 120' \Rightarrow \tau = 1 \\ \text{otherwise } \tau = 0.5 \end{cases} ;$ CT_{BU} = Connecting transfer time for European connections; CT_{INT} = Connecting transfer time for all other connections; $\delta = \begin{cases} \text{if } RF < 1.2 \Rightarrow \delta = 1 \\ \text{otherwise } \delta = 0.5 \end{cases} ;$ RF : routing factor defined as the ratio between the direct distance and the flight's distance;	
Software	Microsoft Access	Medium complexity

3.2.5 Netscan Connectivity

The model is developed by Veldhuis (1997) and owned by SEO Economic Research. The model is to apply in order to evaluate direct and indirect connections. It proposed a scale to the quality of a theoretical direct connection (Veldhuis, 1997). Veldhuis (1997) has presented the model to analyze Amsterdam/Schiphol Airport. Matsumoto et al, has extended this approach to the Asia/Pacific region to measure and compare the performance of airline networks and hub connectivity of selected airports.

Table 3.7 Netscan Connectivity (Redondi and Burghouwt , 2010).

Measure	Netscan	
Main reference	Veldhuis (1997), Matsumoto-De Wit-Burgouwt (2008)	
Applications	Hub connectivity and airport accessibility	
Cut-point conditions	- minimum connecting time (MCT) of 60' for all connections	
Weighting function for every viable connection	$f = \text{QUAL} = 1 - \frac{\text{PTT} - \text{NST}}{\text{MAXT} - \text{NST}} ; \text{ quality index};$ <p style="text-align: right;">NST: non-stop travel time (hours)</p> $\text{PTT} = \text{FLY} + 3 * \text{TRF}; \quad \text{PTT Perceived travel time (hours);}$ <p style="text-align: right;">TRF Connection transfer time (hours); FLY Flying time (hours);</p> $\text{MAXT} = (3 - 0.075 * \text{NST}) * \text{NST};$ <p style="text-align: right;">MAXT: Maximum perceived travel time (hours)</p>	
Software	Microsoft Access	Medium complexity

Netscan proposes a quality index to every individual connection, ranging between 0 and 1. While, a non-stop flight (direct) is given the maximum quality index of 1, an indirect connection will be always given lower than 1 quality index because of additional travel time of transfer time and detour time for the passenger.

The theoretical direct travel time is calculated by the geographical coordinates of origin and destination airport. By taking the product of the quality index and the frequency of the connection per time unit of day or week or year, the total number of connections or connectivity units (CNU) can be derived. Eqs from 3.3 to 3.6 summarize the model.

$$\text{MAXT} = (3 - 0.075 * \text{NST}) * \text{NST} \quad (3.3)$$

$$\text{PTT} = \text{FLY} + (3 * \text{TRF}) \quad (3.4)$$

$$\text{QUAL} = 1 - ((\text{PTT} - \text{NST}) / (\text{MAXT} - \text{NST})) \quad (3.5)$$

$$\text{CNU} = \text{QUAL} * \text{FREQ} \quad (3.6)$$

where,

MAXT: maximum perceived travel time

NST: non-stop travel time

PTT: perceived travel time

FLY: flying time

TRF: transfer time

QUAL: quality index of an individual connection

CNU: number of connectivity units

CHAPTER 4

CASE STUDIES

In this chapter, three case studies based on real data are defined. In the first case, Turkish Airlines' (TK) network performance is compared with the performance of other major airlines operating from hubs in Europe. In the case, comparisons are done using the models of Doganis & Dennis, Bootsma, Weighted and Danesi Connectivity. In the second case, TK's network connectivity performance is measured and evaluated for two schedules: summer 2011 and summer 2012 which are based on different wave structures. In the case, the connectivity measures of two schedules are compared using the models mentioned above and also Netscan model. In the third case, a new weighted connectivity measure which is extending the weighted connectivity function by including transfer passenger ratios and network contribution in terms of passenger revenue which are the most important criteria affecting the success of a network structure. These criteria have not been used before to evaluate network performance in any other research available in the literature.

4.1 KEY QUESTIONS OF THE CASES

In this thesis, network connectivity measures are evaluated based on real data. Three different cases are designed to answer some key questions that would help an airline to evaluate and improve its network connectivity.

The first case is designed to compare TK's network performance with the performance of other major carriers operating at European hubs. The hubs considered are Frankfurt (FRA), Munich (MUC), Amsterdam (AMS), Paris (CDG), Rome (FCO)

and Istanbul (IST). The key question is which airline has more connectivity on the base hub, Airline A at FRA / Airline B at MUC / Airline C at AMS/ Airline D at CDG / Airline E at FCO / TK at IST. The results provide a strategic analysis of Istanbul hub measuring competitive strength with respect to other hubs that are in close geography.

The second case is designed to measure and evaluate the improvement of TK's network performance for summer 2012 schedule compared to summer 2011 schedule which has a different wave structure. The key question is whether changing the wave structure increases the connectivity of TK. The results provide an analysis of evaluating the wave structure in the schedule plan.

The third case is designed to evaluate the proposed method measuring network performance using a new weighted connectivity function that includes transfer passenger ratio and network contribution in terms of passenger revenue. The key question is whether we can design a better and realistic connectivity measure based on TK's strategic objectives. The most important factors affecting the success of a hub-and-spoke network is transfer passenger volumes and total revenue. A new approach including these most important factors is designed in order to evaluate the network connectivity. The case applies this new method to Turkish Airlines schedule and provides the results.

4.2 CASE 1: COMPARING THE PERFORMANCE OF EUROPEAN HUBS

Turkish Airlines network performance at Istanbul (IST) is compared with the other competitors' performance at European hubs, Frankfurt (FRA), Munich (MUC), Amsterdam (AMS), Paris (CDG), Rome (ROM) stated in Figure 4.1.



Figure 4.1 European Hubs.

4.2.1 The Data and Schedules

The flight schedules of airlines based on Frankfurt, Munich, Amsterdam, Paris, Rome and Istanbul are derived from SRS (the Schedules Reference Service) database for the first week of August 2012.

The connections are generated in case of minimum connection time as 60 minutes and maximum connection time as 720 minutes. For the airline based on Frankfurt with a weekly schedule of 196 points, 386,028 meaningful connections are generated. For the airline based on Munich with a weekly schedule of 126 points, 312,516 meaningful connections are generated. For the airline based on Amsterdam with a weekly schedule of 132 points, 259,626 meaningful connections are generated. For the airline based on Paris with a weekly schedule of 145 points, 314,222 meaningful connections are generated. For the airline based on Rome with a weekly schedule of 88 points, 82,297 meaningful connections are generated. For Turkish Airlines based on Istanbul with a weekly schedule of 189 points, 322,769 meaningful connections are generated.

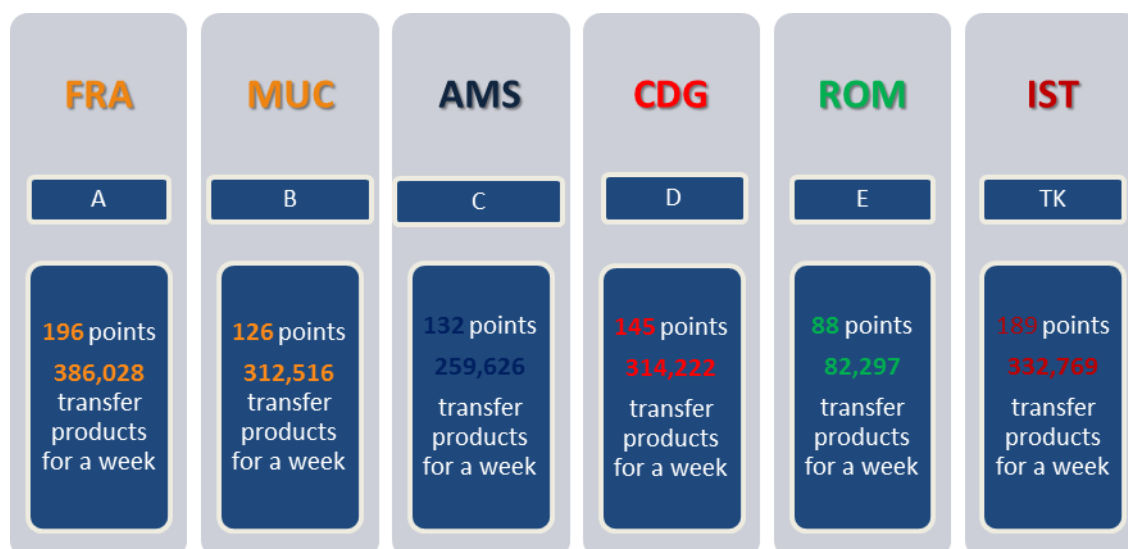


Figure 4.2 The Data & Schedule.

4.2.2 Doganis and Dennis Connectivity

The connections are evaluated for maximum 90 minute connections called Doganis and Dennis connectivity and then, results are compared with the passenger numbers transferred via given hubs that are obtained from reservation systems. Additionally it is compared with the passenger number transferred within connection time 90 minutes. . In Figure 4.3, PAX shows total number of reservation system passenger who took their second flight within 12 hours. In Figure, PAX*90min shows total number of reservation systems passenger numbers who took their second flight within 90 minutes. According to the evaluation, Munich performance gives the best result whereas the biggest number of 12 hour transfer passenger belongs to Frankfurt and also the biggest number of 90 minute transfer passenger belongs to Frankfurt. The performance of Istanbul is the forth on the ranking whereas it is the third on the ranking of total reservation system passenger number, on other hand and it is the last on ranking of transit passenger number within 90 minutes.

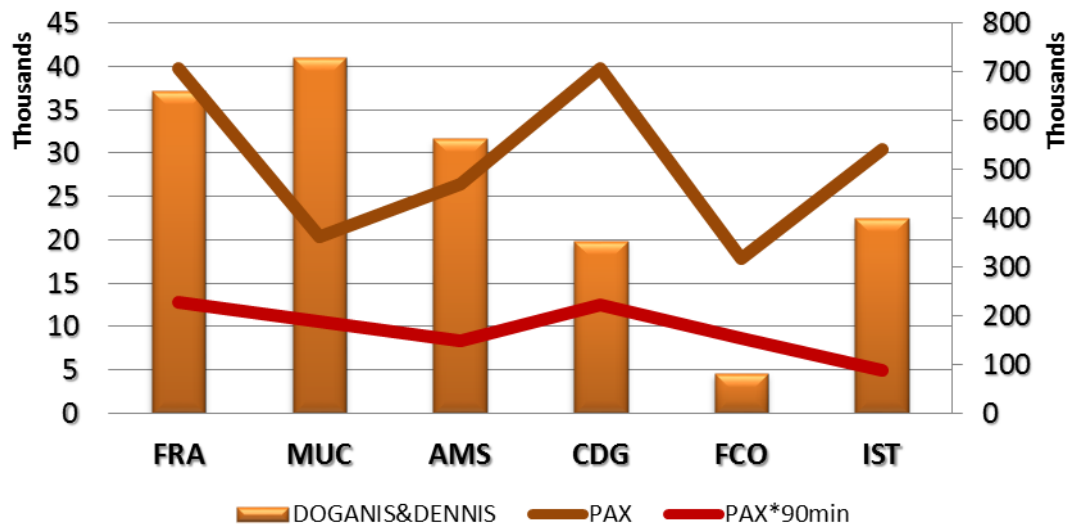


Figure 4.3 Doganis and Dennis Connectivity.

4.2.3 Bootsma Connectivity

The connections are evaluated in respect of connection time differed from regions to region called Bootsma connectivity and then, results are compared with the passenger numbers transferred via given hubs. Additionally it is compared with the passenger number transferred within Bootsma model. In Figure 4.4, PAX shows total number of reservation system passenger who took their second flight within 12 hours. In Figure, PAX*Bootsma shows total number of reservation systems passenger considering the criteria of Bootsma connectivity model. According to the evaluation, Frankfurt performance gives the best result whereas the biggest number of transit passenger belongs to Frankfurt. Istanbul performance is the second on the ranking whereas it is the third on the ranking of total reservation system passenger number and it is the third on ranking of transit passenger number in respect of Bootsma model constraints.

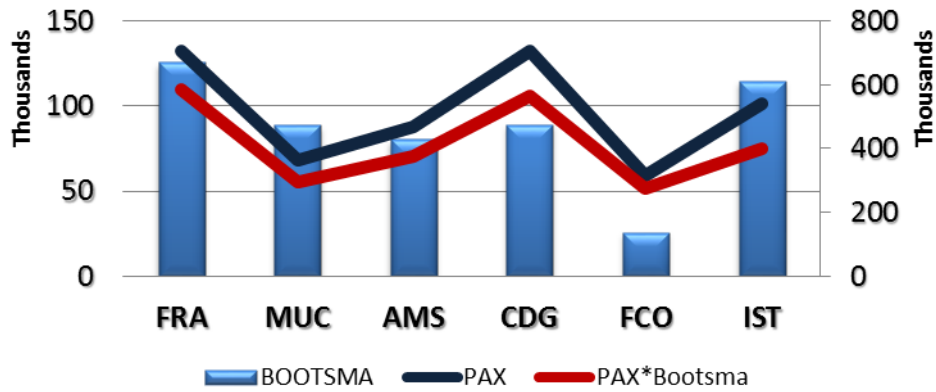


Figure 4.4 Bootsma Connectivity.

4.2.4 Weighted Connectivity

The connections are evaluated in respect of connection time differed from regions to region and also detour factor called Weighted connectivity and then, results are compared with the passenger numbers transferred via given hubs. Additionally it is compared with the passenger number transferred within detour factor equal or smaller than 1.4 . In Figure 4.5, PAX shows total number of reservation system passenger who took their second flight within 12 hours. In Figure, $RF \leq 1.4 * W$ shows total number of reservation systems passenger numbers considering the criteria of Weighted connectivity model. According to the evaluation, Istanbul performance gives the best result whereas the biggest number of transit passenger belongs to Frankfurt. Istanbul performance is the third on the ranking of total reservation system passenger number and it is the third on ranking of transit passenger number in respect of detour constraint stated.

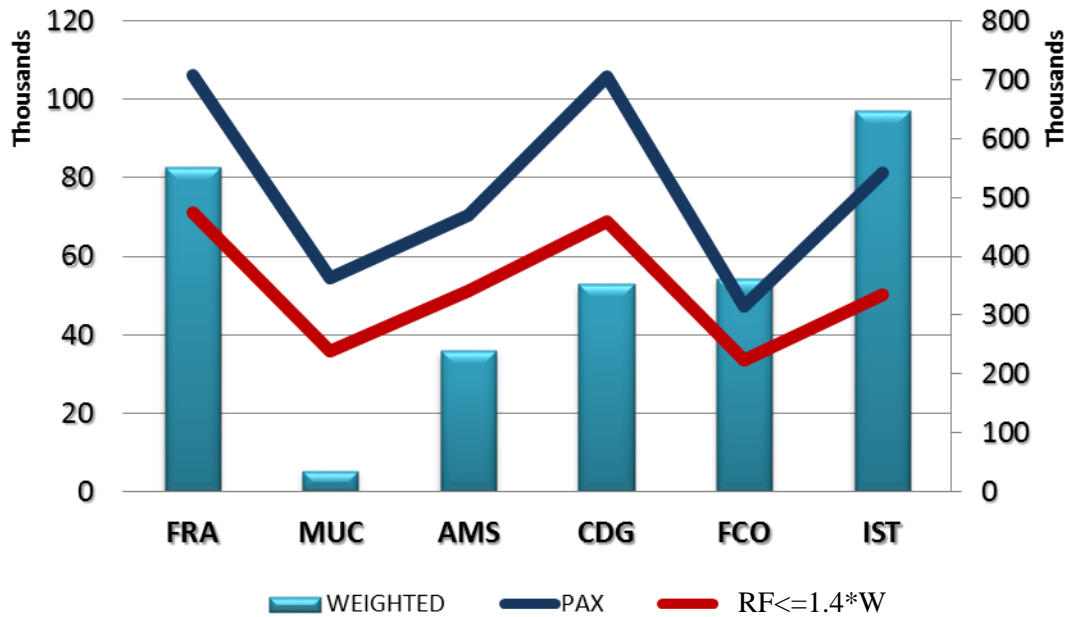


Figure 4.5 Weighted Connectivity.

4.2.5 Danesi Connectivity

The connections are evaluated in respect of connection time differed from regions to region and also maximum detour factor 1.5 called Danesi connectivity. Additionally, the results are compared with the passenger numbers transferred via given hubs. Additionally it is compared with the passenger number transferred within detour factor equal or smaller than 1.5 . In Figure 4.6, PAX shows total number of reservation system passenger who took their second flight within 12 hours. In Figure, RF \leq 1.5*Danesi shows total number of reservation systems passenger numbers considering the criteria of Weighted connectivity model. According to the evaluation, Frankfurt performance gives the best result whereas the biggest number of total transit passenger and transit passenger number within 1.5 detour factor belongs to Frankfurt. İstanbul is the second on the ranking whereas it has approximately the same transit passenger number within 1.5 detour factor constraint.

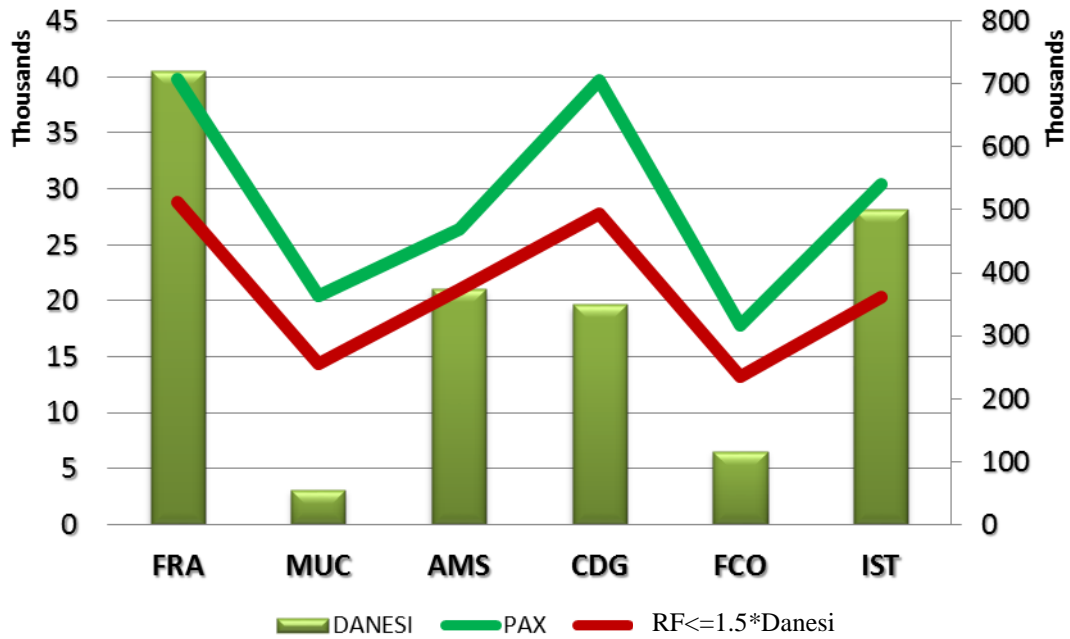


Figure 4.6 Danesi Connectivity.

4.2.6 Summary of Case1

Four different methods provide different evaluations depending on the main criteria that are measured with the function of the model. Therefore, in order to validate the results of all methods and decide which hub has the highest connectivity, total number of passengers transferred at each hub (obtained through reservations systems) within 12 hours is used. Based on the transfer passenger volumes, the best hubs are Frankfurt, Paris, Istanbul, Munich and Amsterdam in order. Therefore, it is expected that connectivity values to be in parallel with this order.

Based on the Doganis & Dennis model, Munich hub has the highest grade of connectivity. Since in this model only the maximum connection time of 90 minutes is used to evaluate, it can be concluded that Munich provides the maximum connection within 90 minutes. However, Munich is not best in terms of total number of transfer passengers. Therefore, it can be concluded that not only the 90 minute connection time is the main parameter to evaluate connectivity.

The Bootsma method concludes that Frankfurt is the best hub and Istanbul is the second best hub. This result is actually parallel to the comparison done using transfer passenger volumes.

Weighted connectivity is a model that considers the detour advantage of hubs. Based on this model, Istanbul has the best connectivity rate which is reasonable when the geographical location of Istanbul is considered.

Danesi connectivity model is an advanced version of weighted connectivity. The model separates detour advantage of hubs into two groups. . Frankfurt is the best based on the results. Istanbul is found to be the second best hub. The results are comparable with the real time transfer passenger rankings.

With this case study, it can be seen that different models tend to provide different results depending on the factors considered. Therefore, it is important to understand the factors affecting passenger choices and design the network with the objective of maximizing the total number of passengers who are willing to use the hub.

4.3 CASE 2: EVALUATING NETWORK PERFORMANCE FOR TWO DIFFERENT SCHEDULES WITH DIFFERENT WAVE STRUCTURES

The general wave design of Turkish Airlines was restructured in summer 2012 schedule. This case aims to measure the improvement of Turkish Airlines' network performance for summer 2012 compared to summer 2011. Using 5 different connectivity measures, the effect of changing the wave structure is evaluated.

4.3.1 The Data and Schedules

The flight schedules of summer 2011 and summer 2012 are derived from SRS (the Schedules Reference Service) database and compressed schedule into a week in terms of maximum frequency of the route during summer period.

The subregions of the study are specified as America (AA), Middle and South Africa (AF), Middle-East (ME), Commonwealth of Independent States (CIS), Domestic

within Türkiye (DOM), Far East (FE), Middle East (ME), North Africa (NAF), South Asia (SA).

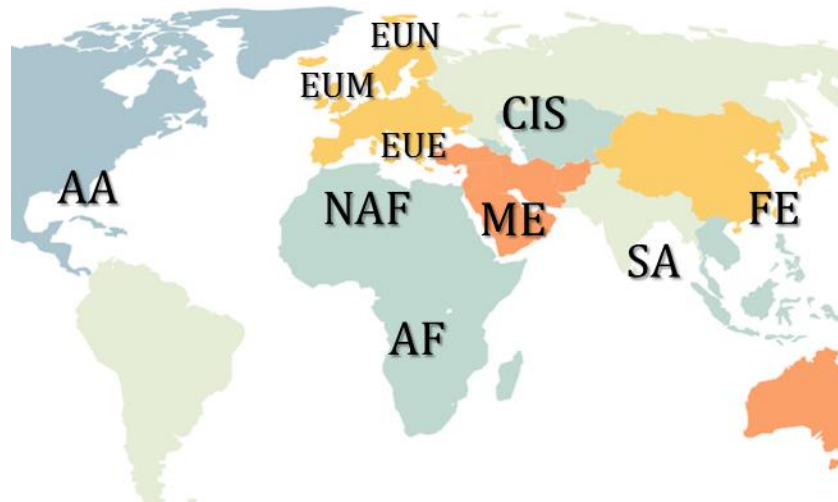


Figure 4.7 Sub-Regions for the Evaluation.

Indirect connections have been constructed using an algorithm, which identifies for each incoming flight at an airport the number of outgoing flights that connect to it by the help of SAS program. The algorithm takes into account minimum connection time and puts a limit on the maximum connecting time and routing factor.

4.3.2 Doganis & Dennis Connectivity

The connections are evaluated among subregions in respect of 90 minutes as maximum connection time. Additionally, the change of network performance between the seasons is shown as percentage. According to the evaluation, domestic flights have the biggest connectivity. It is followed by EUM and then ME on both seasons. The more important point is the improvement between the schedules of summer 2011 and summer 2012. The line in Figure 4.9 shows the difference of the evaluation among subregions by percentage. The best improvement among subregions belongs to AA. It is followed by NAF and then comes EUE.

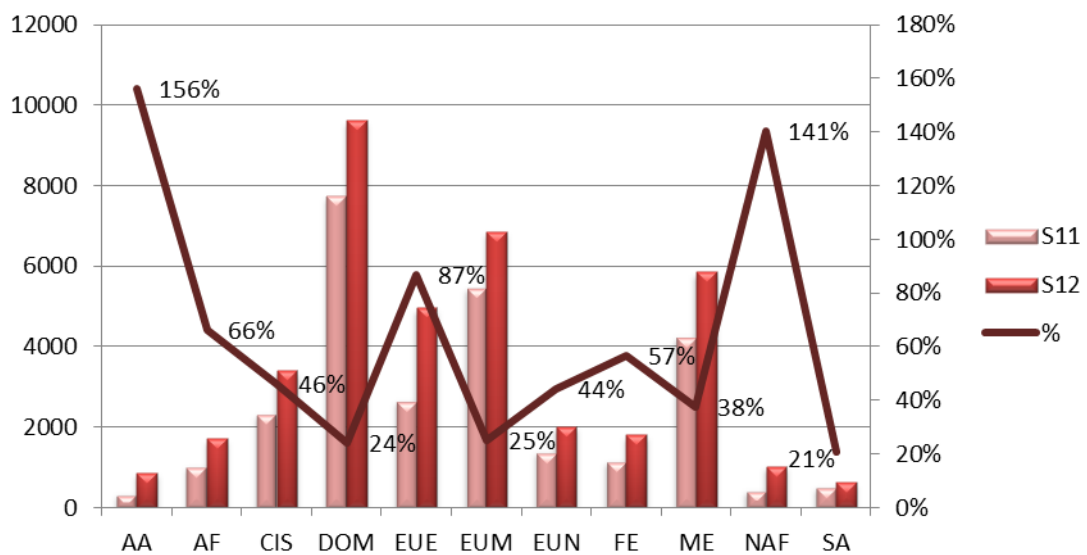


Figure 4.9 Doganis and Dennis Connectivity.

4.3.3 Bootsma Connectivity

The connections are evaluated among subregions by the help of Bootsma model grouping for the connection areas. The change of network performance between the seasons is shown as percentage in Figure 4.10. According to the evaluation, domestic flights have the biggest connectivity. It is followed by ME and then EUM on both seasons. The more important point is the improvement between the schedules of

summer 2011 and summer 2012. The best improvement among subregions belongs to NAF. It is followed by AF and then comes AA.

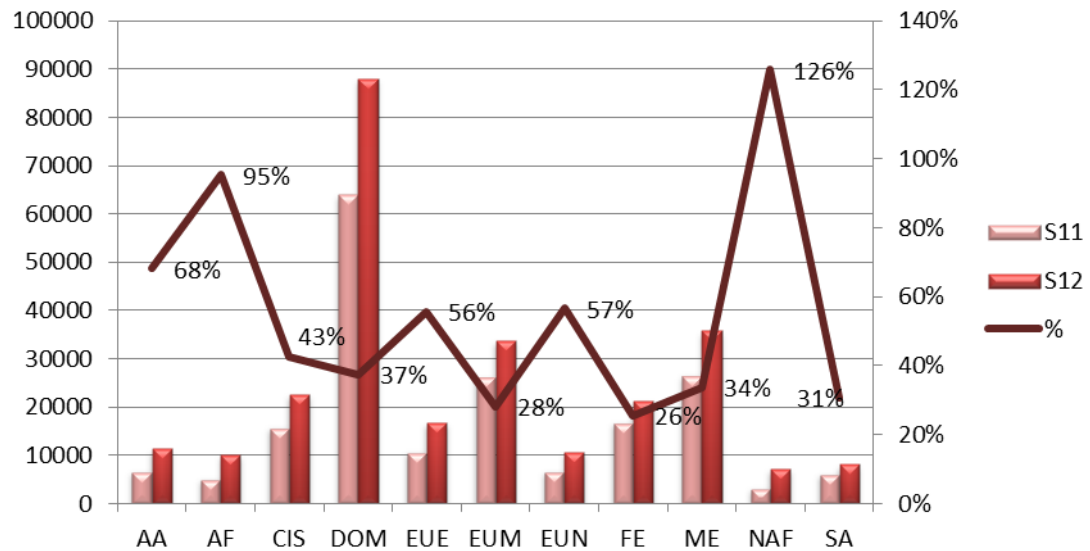


Figure 4.10 Bootsma Connectivity.

4.3.4 Weighted Connectivity

The connections are evaluated among subregions considering Weighted connectivity model grouping and also maximum routing factor as 1,4 as a constraint for the connection areas. Additionally, the change of network performance between the seasons is shown as percentage in Figure 4.11. According to the evaluation, domestic flights have the biggest connectivity. It is followed by ME and then EUM on both seasons. Since the more important point is to analyze whether the new design presents better connections, all regions show an improvement. The best improvement among subregions belongs to NAF. It is followed by AF and then comes AA.

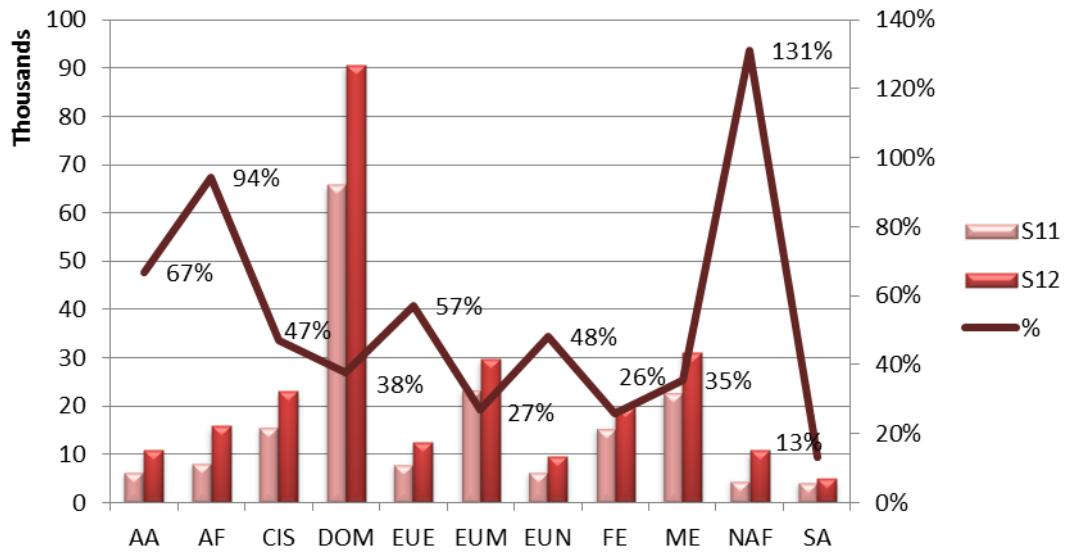


Figure 4.11 Weighted Connectivity.

4.3.5 Danesi Connectivity

The connections are evaluated among subregions by the help of Danesi connectivity model criteria which considers a grouping and also maximum routing factor as 1,5 as a constraint for the connection areas. Additionally, the change of network performance between the schedules is shown as percentage in Figure 4.12. According to the evaluation, domestic flights have the biggest connectivity. It is followed by EUM and then ME on both seasons. Since the more important point is the improvement of the new wave design of the summer schedule, the best improvement among subregions belongs to NAF. It is followed by EUE and then comes AA.

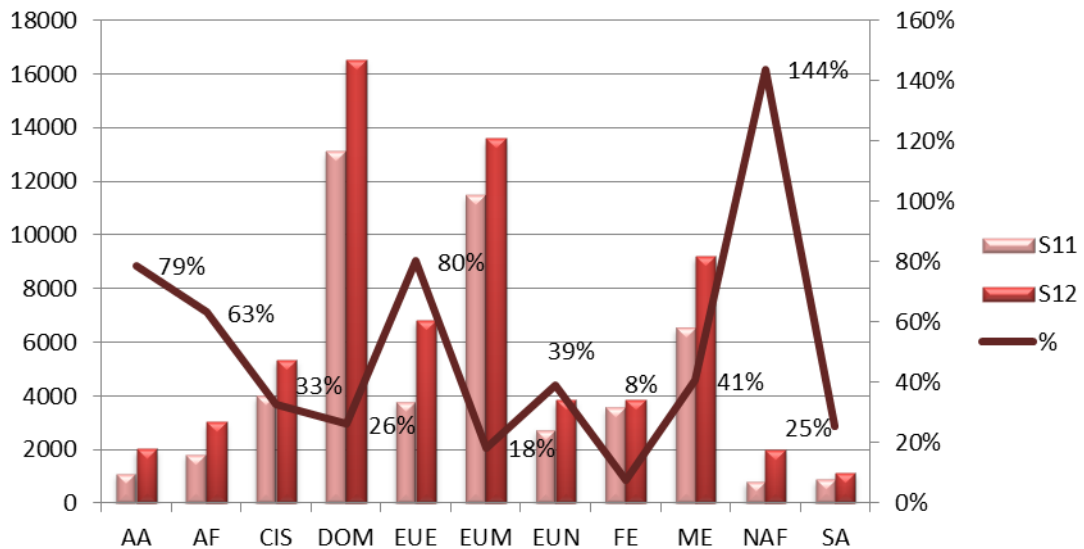


Figure 4.12 Danesi Connectivity.

4.3.6 Netscan Connectivity

The connections are evaluated among subregions in respect of Netscan connectivity unit model. Additionally, the change of network performance between the seasons is shown as percentage in Figure 4.13. According to the evaluation, domestic flights have the biggest connectivity. It is followed by EUM and then ME on both seasons. The more important point is the improvement between seasons than the sub total evaluation of subregions. The best improvement among subregions belongs to NAF. It is followed by AF and then comes AA.

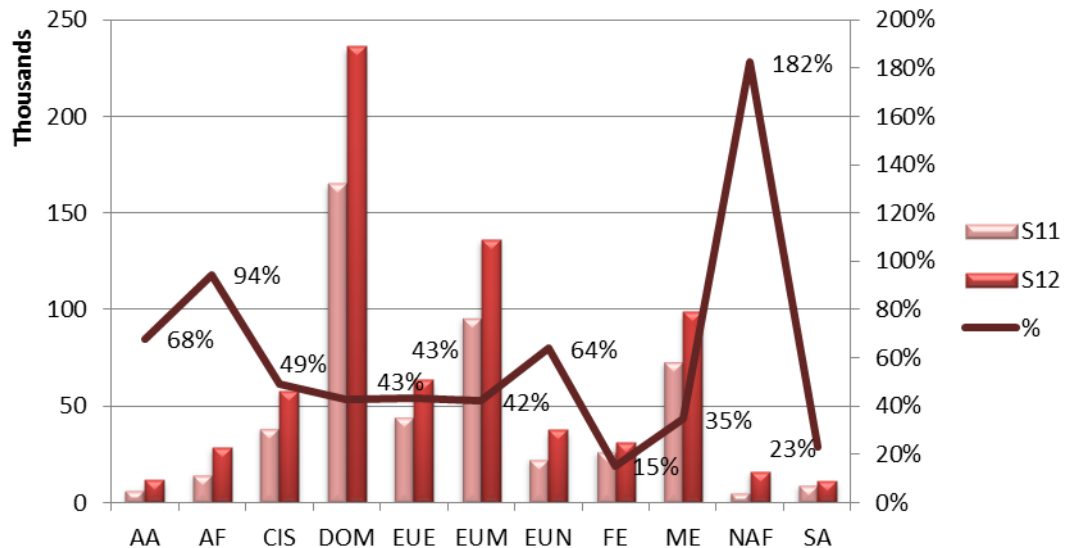


Figure 4.13 Netscan Connectivity.

4.3.7 Summary of Case 2

In this case, each region investigated separately in order to understand the connectivity improvement for each region and find out which region's improvement is more. Ultimately, the analysis is aiming to show that whether the strategic objectives are achieved with the restructuring of the wave.

Table 4.2 shows the comparison of the results of each model for each subregion. Additionally, Table 4.2 presents the change of transfer passenger numbers between the seasons in order to use a metric to evaluate validity of the results of each model.

For the region AA, model Danesi gives the closest result according to the number of transit passenger change. Since Danesi model considers detour factor, it can be derived that generally new wave has considered AA connections and provided a better connectivity for AA.

Table 4.2 Comparisons of the Models.

	DOGANIS&DENNIS	BOOTSMA	WEIGHTED	DANESI	NETSCAN	PAX%
AA	156%	68%	67%	79%	68%	77%
AF	66%	95%	94%	63%	94%	54%
CIS	46%	43%	47%	33%	49%	40%
DOM	24%	37%	38%	26%	43%	21%
EUE	87%	56%	57%	80%	43%	51%
EUM	25%	28%	27%	18%	42%	36%
EUN	44%	57%	48%	39%	64%	62%
FE	57%	26%	26%	8%	15%	26%
ME	38%	34%	35%	41%	35%	32%
NAF	141%	126%	131%	144%	182%	62%
SA	21%	31%	13%	25%	23%	64%

For the region AF, Danesi gives the closest result according to the number of transfer passenger change. The second closer result belongs to Doganis & Dennis model. While Danesi considers detours and Doganis & Dennis considers connection time of maximum 90 minutes, it can be derived that the new wave structure redesigned the AF connections in terms of waiting time and detour advantage.

For the region CIS, Bootsma gives the closest result according to the number of transfer passenger change. While Bootsma considers the grouping of regions in terms of waiting time, it can be understood that the new wave structure redesigned the CIS connections in terms of waiting time grouping as stated in Bootsma model.

For the region DOM, Doganis & Dennis gives the closest result according to the number of transit passenger change. While Doganis & Dennis considers connection time of maximum 90 minutes, it can be concluded that the new wave structure redesigned the DOM connections considering the objective of reducing waiting time.

For the region EUE, Bootsma gives the closest result according to the number of transfer passenger change. Since Bootsma considers the grouping of regions in terms of waiting time, it can be obtained that the new wave structure redesigned the EUE

connections considering the objective of waiting time grouping as stated in Bootsma model.

For the region EUM and EUN, Netscan gives the closest result according to the number of transit passenger change.

For the region FE and ME, Bootsma gives the closest result according to the number of transfer passenger change. Since Bootsma considers the grouping of regions in terms of waiting time, it can be concluded that the new wave structure redesigned the FE and ME connections in terms of waiting time grouping as stated in Bootsma model.

For the region NAF and SA, none of model gives an approximate result. The gap between the real numbers and evaluation is very big due to the fact that the total frequency number of region NAF has been increased with new destinations. For the region SA connectivity has improved only with a percentage between 13 and 25. This increase is lower compared to other regions. This is due to the limited number of frequency.

4.4 CASE 3: NEW NETWORK CONNECTIVITY MEASURE INCLUDING TRANSFER PASSENGER AND REVENUE INFORMATION

In this research, it has been realized that none of the available methods measuring connectivity uses transfer passenger and revenue information which are actually the main objectives in real life. Airlines operating through a network want to maximize total revenue and increase load factors with total transfer passengers. Therefore, a model which measure network connectivity performance based on revenue and transfer passenger will be more realistic and applicable to real life.

In this case, a new connectivity function is designed by including transfer passenger ratio and network revenue contribution effects on airline subregion groups.

Since Netscan assigns to each direct and indirect connection a quality index, ranging between 0 and 1, only online connections are considered as viable connections; the new weighted connectivity function is obtained by taking this model as a base.

4.4.1 The methodology

The flying points are grouped to subregions as AF, CIS, DOM, EUE, EUM, FE, ME, NAF, SA. 11 (the number of sub regions) times 10 (number of beyond regions of any subregion), totally 110 pairs are considered to weight passenger change and network contribution change, additional revenue of passenger for transfer point. The beyond passenger ratio is defined as transit passenger number for beyond region is over total transit passenger number of that subregion defined in Eq.(4.1). Additionally, network contribution ratio is also defined as transit passenger revenue for beyond region is over total transit passenger revenue of that subregion defined in Eq.(4.2).

Table 4.3 Example of Weighted Function.

		pax %	network contribution %
BEYOND			
AA	AF		
	CIS		
	DOM		
	EUE		
	EUM		
	EUN		
	FE		
	ME		
	NAF		
	SA		
	SUBTOTAL		

$$WP_{\text{beyond}} = P_{\text{beyond}} / \sum P_{\text{beyond}} \quad (4.1)$$

$$WR_{\text{beyond}} = R / \sum R \quad (4.2)$$

$$W = (1 + WP_{\text{beyond}}) * (1 + WR_{\text{beyond}}) \quad (4.3)$$

$$W_{\text{CNU}} = \text{CNU} * W \quad (4.4)$$

where,

WP_{beyond} Beyond passenger weight

P_{beyond} Beyond passenger number of sub region

WR_{beyond} Beyond network contribution weight

R: Beyond transit passenger revenue of sub region

W The proposed weight

W_{CNU} The proposed coefficient

Weight of our proposed methodology is defined as the sum of beyond passenger weight and beyond network contribution weight as stated on (Eq. 4.3). Finally, weighted CNU is obtained from Netscan CNU multiplied by the proposed weight (Eq. 4.4).

4.4.2 The Results

The schedules of summer 2012 and summer 2011 are evaluated considering the proposed methodology and the results among subregions are given in Figure 4.14. Since the aim of this method is to present whether the new design shows any improvement among regions considering transfer passenger volume and transfer passenger additional revenue volume for its beyond region.; the line in Figure 4.14 shows the difference of the results for each region evaluation. NAF shows the biggest improvement with %163, secondly AF with % 96, thirdly AA with %66. They are followed by respectively; EUN, CIS, DOM, EUM, EUE, ME, SA, and FE.

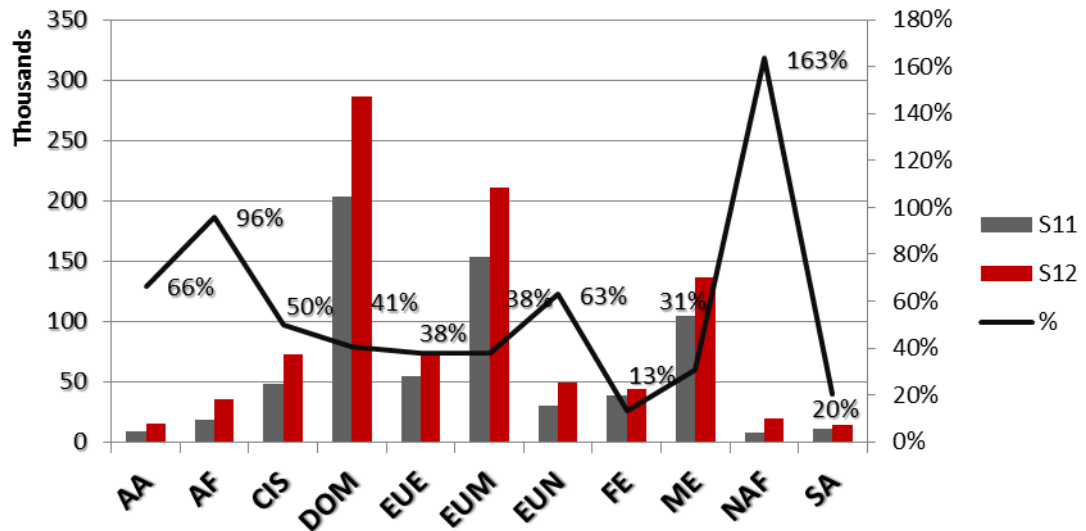


Figure 4.14 Comparison of S11 and S12.

4.4.3 Summary of Case 3

The proposed methodology is compared with the change of transfer passenger number, the change of network contribution and CNU of Netscan model using the summer 2012 and summer 2011 schedules. The connectivity measure of the new method is better aligned with the transfer passenger volumes. This proves that the new method's results are valid.

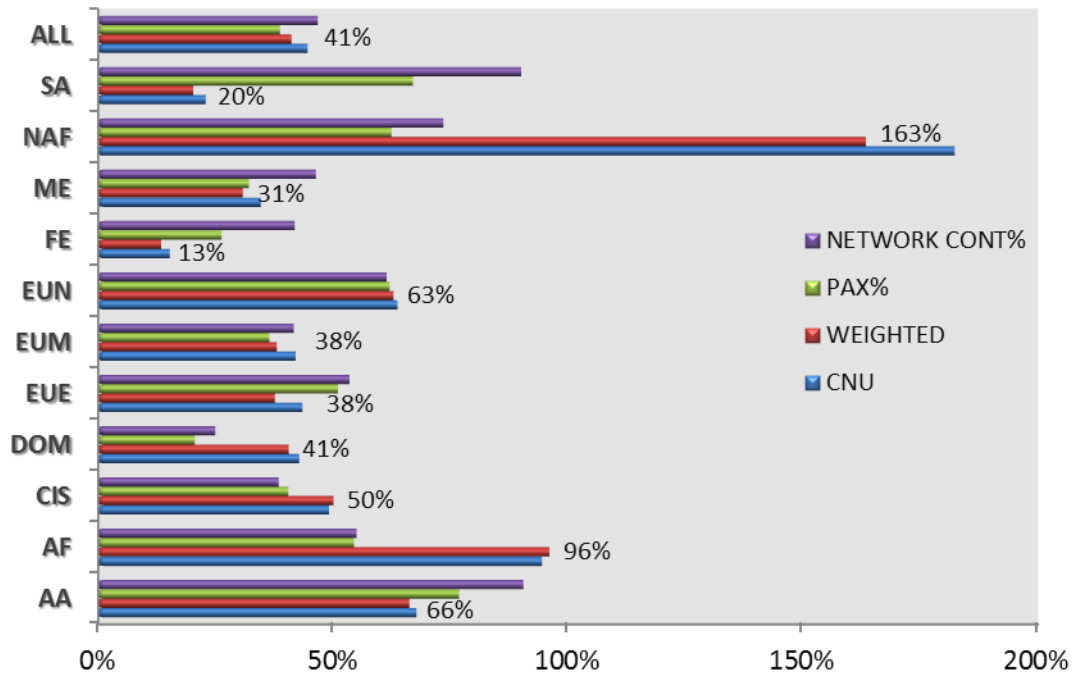


Figure 4.15 Comparisons for the Proposed Methodology.

The best results belong to the regions ME, EUN, EUM, furthermore a better results than classic Netscan model belongs to NAF and DOM in terms of passenger change. On the other hand, better result than classic Netscan model belongs to the regions NAF, EUN and DOM.

Generally, for the regions that do not have frequency change in common, the proposed methodology gives closer results to the passenger numbers. The proposed model gives better results for the regions that show almost no frequency difference. This shows that actually new method normalizes the effect of frequency increase and focuses on the real transfer passenger and revenue impact in the network.

CHAPTER 5

CONCLUSIONS

The competition among airlines and airports has been changed in a constructive way by the growth of hub-and spoke network model. For the airlines and airports, the competitive position of has been usually analyzed or evaluated in terms of aircraft movements, frequencies of destinations, number of passengers or cargo volumes. Although these indicators are valuable in themselves, they do not give any information on the strength of wave design, connection functionality, and effectiveness of connectivity for airline networks and the competitive position of hub airports.

To evaluate the performance of network structure, some researchers suggests methods to measure the network connectivity. In this research, methods used to measure network connectivity are reviewed and some of these methods are applied for real data. Three case studies based on real data are designed to answer different questions or needs in evaluating the network performance of an airline's schedule. The case studies show how can these researches presenting methods to measure network connectivity be used in real life applications in order to analyze an airline's competitive position and plays a decision support tool in designing networks. The analysis done with the case studies provide answers to some strategic questions that are asked to evaluate performance of an airline's network. In addition, the case studies prove that not all methods measuring connectivity give the same results. Each method can look at the network performance from different views and airline can choose the right method or methods based on its strategic objectives in designing the network.

In the first case, TK's network performance is compared with other competitors' performances at European hubs using 4 different models which are Doganis & Dennis, Bootsma, Weighted Connectivity and Danesi Connectivity. The results show that each

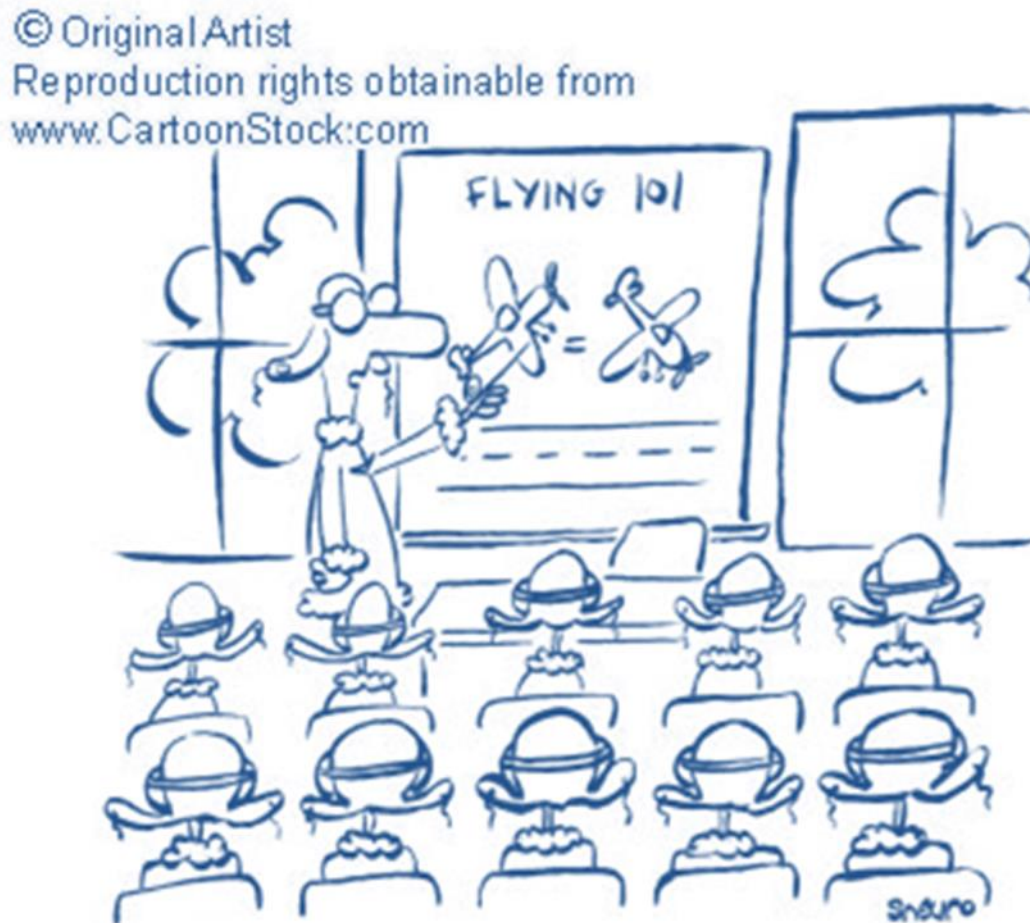
model assigns different connectivity values to the hubs. The best hub changes depending on the factors considered in the model. Based on the analysis, it is concluded that Frankfurt hub is the first hub and Istanbul is the second hub in terms of detour factor, transfer passengers and waiting times. Istanbul is the best hub if only the detour factor is used which is expected because of the geographical advantage of Istanbul. Also, from this case, it is seen that Bootsma model which is one of the basic models gives connectivity ranking which is closest to the ranking obtained using actual passenger numbers.

In the second case, it is aimed to measure the improvement of TK's network performance with the new wave design. Also, the analysis is done by dividing the network into regions in order to evaluate whether the strategic objectives of new wave are reached or not. Summer 2011 schedule which is based on the previous wave structure is compared with the summer 2012 schedule with new wave structure. Results of 5 different models for each region is analyzed and compared with the total number of transfer passenger volumes to check the validity of the results. All models concluded that summer 2012 has much better connectivity compared to summer 2011 schedule. This connectivity improvement is found to be a lot more than increase in the number of frequency. In addition, analysis shows that the region-based strategic objectives of changing the wave have been achieved.

In the third case, a new method including transfer passenger volume and revenue effect is designed and tested. None of the methods in literature considers these factors. Since these two factors are one of the main objectives for network carriers, it is believed that this new method can be more applicable for real instances. The new method gives results which are comparable with Netscan model and transfer passenger volumes which prove the validity of the model. In addition, the results show that the method is less sensitive to frequency increases but more focused to transfer passenger and revenue.

In the literature, there are researches evaluating network performance. However, this research applies these methods to real life instances and shows how can the results can help to answer some real life concerns of network planners and can be used as a decision support tool. This study may be helpful for airlines in identifying their network performance and competitive position to determine the connections by revenue side and

also may be helpful for airports or airlines in identifying their network performance and competitive position in relation to competing airports or airlines.



"Remember, always try to keep the number of landings you make equal to the number of take offs you make."

Figure 5.1 Cartoons (Sneuro).

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