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THE NETWORK ANALYSIS OF THE DOMESTIC AND INTERNATIONAL AIR TRANSPORTATION STRUCTURE OF TURKEY

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Abstract

Considering the effectiveness of air transportation, the investigation of the dynamics of flight routes are having a great attention, lately. Even several studies are conducted in a global scale, some hubs are required more consideration in inter-city and inter-country transportation. According to the study of [Song and Yeo], İstanbul located in Turkey has the maximum degree centrality among 1.060 airports and maximum betweenness centrality among the top 30 airports. In this study, we aim to see the air transportation network structure deeply for this country depending on its topographic characteristics. For this purpose, social network analysis is used as an analysis method and visualization tools to describe the correlation structure of the data. Thus, we illustrate some of the network-level and node-level metrics in aforementioned analysis by exploring route connections among airports. Additionally, the network maps are depicted to better understand the air routes structure. The results indicate that İstanbul has a huge impact among airports in terms of both domestic and international transportation depending on the empirical data of Turkey for the year of 2014. Classifying by countries, Germany and Cyprus has the largest connection measurement results with Turkey.

Keywords: Social network analysis, Air transportation, Turkey, Centrality

TÜRKİYE'DE YEREL VE ULUSLARARASI HAVA TAŞIMACILIĞI YAPISININ AĞ ANALİZİ İLE İNCELENMESİ

Öz

Hava taşımacılığının etkinliği düşünüldüğünde, uçuş rotalarının dinamiklerini incelenmesi, son zamanlarda, hayli ilgi çekmektedir. Küresel ölçekte çok sayıda çalışma yapılsa da, bazı merkez havalimanlarının şehirlerarası ve ülkeler arası taşımacılıkta daha fazla düşünülmesi gerekmektedir. Song ve Yeo'nun çalışmalarına göre, Türkiye'de bulunan İstanbul şehri, dünyada 1.060 havalimanı arasında en yüksek merkezilik ve ilk 30 havalimanı arasında en yüksek arasındalık merkeziliğine sahiptir. Bu çalışmada, topografik özelliklerine bağlı olarak bu ülkenin hava yolu ağ yapısının incelenmesi hedeflenmektedir. Bu amaçla, sosyal ağ analizi, verinin korelasyon yapısını tanımlamada görselleştirme araçları ve bir analiz yöntemi olarak kullanılmıştır. Böylece, havaalanları arasında rota bağlantılarını araştırarak, yukarıda bahsedilen analizde ağ seviyesindeki ve düğüm seviyesindeki bazı ölçütler açıklanmıştır. Ek olarak, ağ haritaları, hava yolları yapısını daha iyi anlamak için tasvir edilmiştir. Sonuçlar, İstanbul'un 2014 yılı için Türkiye'nin ampirik verilerine göre hem yerel hem de uluslararası taşımacılık açısından havaalanları arasında büyük bir etkiye sahip olduğunu göstermektedir. Ülkelere göre sınıflandırıldığında ise, Almanya ve Kıbrıs, Türkiye ile en büyük bağlantı ölçüm sonuçlarına sahiptir.

Anahtar Kelimeler: Sosyal ağ analizi, Hava taşımacılığı, Türkiye, Merkezilik

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1. Introduction

Airline transportation is a crucial asset for a country in smaller or larger scales. Economic and social factors are triggers of the increase in the demand for the air transportation. Even there is not a common solution for a general framework, there is a ''do less for additional'' impact of distinguishing critical airports while dealing with the air transportation system [1]. Critical airports may be defined with higher degree and betweenness centralities which are topological structures of the network. They provide us with understanding how these airports directly connected to others and their intermediate roles between others.

In addition to Worldwide Air Network (WAN) studies [2, 3], several studies include a single country or continent air network traffic [4-7]. Regional air network structures may be different from the WAN and/or each other, so they are required some separate research. As an example, there has been a huge development in the Air Network of China (ANC) [5] with the increase in the air routes; while the number of air routes has been decreased in the Air Network of Brazil (ANB) because of the cost-effective strategies [7].

Amongst regional studies, Bagler [6] concludes complex dynamics with small-world network properties and hierarchy of its topology for Air Network of India (ANI). The study of Cheung and Gunes [8] analyze the resilience of the United States air transportation by removing some airports in the network for a specific time point. On a continental scale, Lordan and Sallan [4] explore the Air Network of Europe (ANE) with several layers and topographic properties. İstanbul is listed as one of the core cities of ANE in this study.

We use a specific time point similar to [6, 8], since it is not expected to have a great difference between time points for this type of data sets. We prefer to use the latest available data which is in 2014 for the Airline Network of Turkey (ANT) to present domestic and international evaluations.

1/5 of the population of Turkey lives in İstanbul and it is unique for being the only city having lands both in Europe and Asia. Therefore, it is expected to observe a core or a bridge role for this city. Also, in the very near future (October 2018-expected), the main airport in İstanbul named Atatürk Airport will be terminated, and a new one will be launched, instead. Therefore, it is important to examine the structure of the airports of this city. In the study of Guimerá and Amaral [9], it is implied that the most-central cities are not found to be the most-connected ones but this finding does not match with İstanbul in international scale. However, even it is not in the center of Turkey, it is the most-connected one in domestic scale consistent with Guimerá and Amaral [9]'s study results. Additionally, combining the route data of Alliance, Oneworld, and Sky Team indicates that İstanbul has the maximum degree centrality among 1,060 airports globally and the maximum betweenness centrality among the top 30 airports in the world [2].

The airports with the highest centrality measures are not located in the central or in the middle of other airports for our air network. This feedback leads us to conclude that the population or economical prepotency over geography for air networks. Depending on the centrality and clustering measures, we are not able to conclude any small-world or hierarchical structure for this network. It has one main hub and the majority of the airports has one connection to this main hub.

The rest of the paper is organized as follows. Section 2 describes the methodology in general with the data, mathematical preliminaries of social network and centrality subtitles. Analysis results, statistical distributions and correlations are given in the third section with the visual representations domestically and internationally. Finally, section 4 includes the conclusion part of the study.

2. Methodology

2.1. Data

In order to analyze ANT, 2014 WAN dataset were obtained from openflights.org. In these datasets, there are three categories, which are movement, passenger and cargo. Database contains 67,663 routes between 3,321 airports on 548 airlines spanning the globe.

In this study, airports which were located in Turkey and have only inter-country flights routes were selected. Thus, 53 airports and 280 inter-country routes were taken into consideration in the social network analysis.

2.2. Mathematical Preliminaries of Social Network

To represent a social network, let a directed or undirected graph $G = \{V, E\}$, where $V = \{v_1, v_2, \dots, v_n\}$ is a set of nodes (vertex) and $E = \{e_1,, e_2, \dots, e_m\}$ is a set of edges (links) in the graph. Each node indicates actors such as a person or locations (airports in our case) and each edge indicates the relationship between them (flight routes in our case). One of the simplest way to represent graphs is to use an adjacency matrix which is denoted by $A = \{a_{ij}\}$ and $a_{ij} \in R^n$ [10]. Then A is defined as

$$A = \begin{cases} a_{ij} = 1, & \textit{if there is a link between nodes i and j} \\ 0\ , & \textit{otherwise} \end{cases}$$

2.2.1. Centrality

Centrality measure, the basic concept of network analysis, is defined only on nodes. It plays an important role in social network analysis. The more central the node is, the more important it is to demonstrate in network structure. The calculated centrality values for nodes are solely comparable among the individuals in the network [11, 12].

Degree centrality: The simplest and the fundamental criterion about a node in a network is the degree of the node. Degree centrality is a useful measure to identify with actors in a network.

Let $A \in R^{n \times n}$ is the adjacency matrix, $k \in R^n$ is the degree vector and $e \in R^n$ is the all-one vector as a weighted vector. Accordingly, the degree centrality of a node for undirected graph is defined as follows:

$$k = Ae$$

Provided that A and e are the same, $k^{in}, k^{out} \in R^n$ is the in-degree and out-degree vectors, respectively. If there is a link from j to i, A_{ij} takes a value of 1 [11]. Then, the degree centrality of a node for directed graph is expressed as:

$k^{out} = A^T e\ (column\ sum\ of\ A)$,
$k^{in} = Ae\ (row\ sum\ of\ A)$,
$k = k^{in} + k^{out}$.

A node having more connections tend to be more powerful in the network structure.

Betweenness centrality: Betweenness centrality is not concerned with the closeness of one node to other nodes, but it measures all shortest paths (geodesic distances) between two nodes. To control over the flow of information in network, nodes with a high betweenness centrality indicates that they are located on the important communication path.

Let Q_{st} be the total number of shortest paths from node s to node t, $Q_{st}(i)$ be the number of shortest paths between two nodes that pass through node i. The betweenness centrality of node i is given by the expression [13]:

$$k_b(i) = \sum_{s \neq t \neq i} \frac{Q_{st}(i)}{Q_{st}}$$

Accordingly, the most central node is the node with the highest value in betweenness centrality [14].

3. Analysis and Findings

The main focus of this study is to define the domestic and international high impact airports in terms of their topographic characteristics of the ANT structure. For this aim, social network analysis is used to define these airports in addition to visual representations. Gephi 0.9.2 is used for statistical analysis and R Studio (igraph package) is used for visualizations [15].

3.1. International network structure

Figure 1 shows the visualization network analysis map of all international airports with its connections in Turkey. It has direct flights to almost all continents.

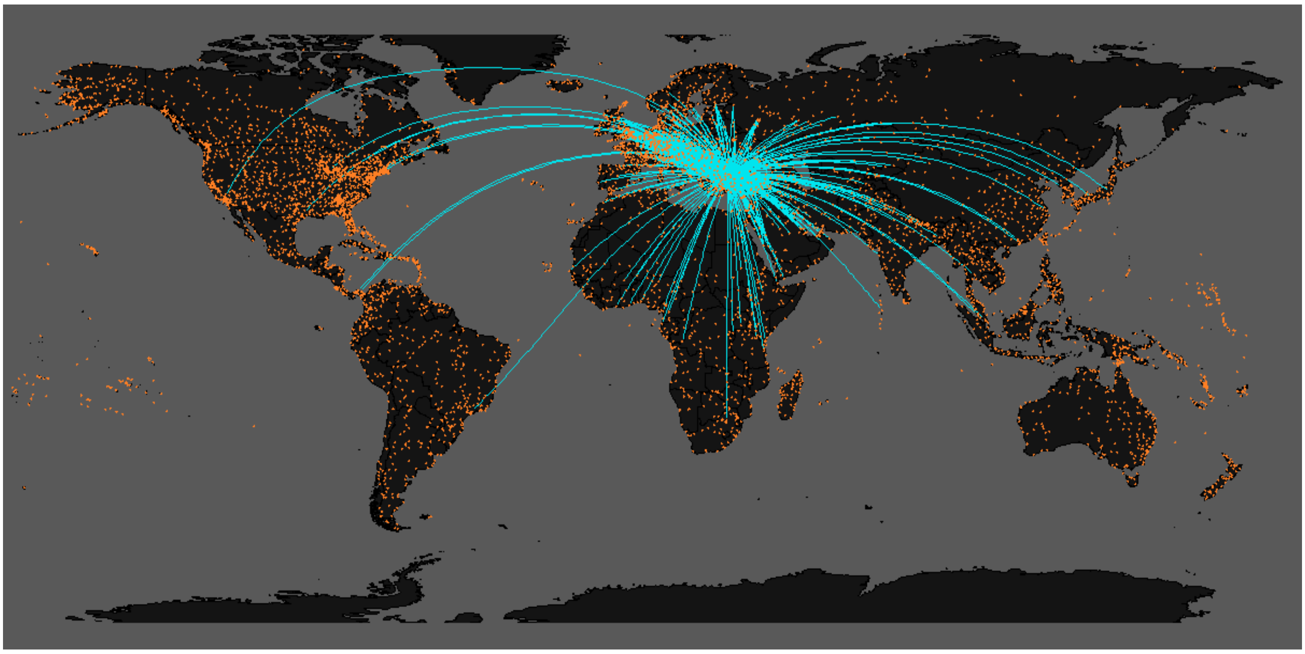


Figure 1. Network analysis map of the airport in Turkey.

Table 1 shows the topography of the domestic and international graph properties of Turkey. The number of air flights in and out of Turkey is 271 and the total number of flight routes is 1,661. The average of all shortest paths (geodesic distances) between nodes is 321.57; while the number of average connections is 7.62. The average in and out degrees of the network are both found to be 3.81. The clustering coefficient is calculated to be 0.23. The corresponding network may not have a small-world or hierarchical structure because of having low clustering scale for the corresponding network [16].

Table 1. Air transportation network characteristics.

Graph Structural Properties	
Airports	271
Flight routes	1661
In degree centrality	3.81
Out degree centrality	3.81
Clustering coefficient	0.23
Average degree centrality	7.62
Average betweenness centrality	321.57

Table 2 shows the top 20 airports based on degree centrality. According to this table, İstanbul Atatürk Airport is ranked as the first amongst all airports, followed by İstanbul Sabiha Gökçen Airport, Antalya, İzmir and Ankara, respectively. Among the top 20 airports, 11 airports are from Turkey in terms of degree centrality. Concerning international flights with Turkey, Duesseldorf and Nicosia have the highest degree centralities with 16.

Table 2. Degree centrality of the top 20 airports.

Rank	Airport	Country	Degree Centrality
1	İstanbul Atatürk Airport (IST)	Turkey	437
2	İstanbul Sabiha Gökçen Airport (SAW)	Turkey	194
3	Antalya (AYT)	Turkey	126
4	İzmir (ADB)	Turkey	87
5	Ankara (ESB)	Turkey	80
6	Dalaman (DLM)	Turkey	56
7	Bodrum (BJV)	Turkey	41
8	Adana (ADA)	Turkey	20
9	Duesseldorf (DUS)	Germany	16
10	Nicosia (ECN)	Cyprus	16
11	Hatay (HTY)	Turkey	16
12	Amsterdam (AMS)	Holland	15
13	Trabzon (TZX)	Turkey	14
14	Brussels (BRU)	Belgium	12
15	Frankfurt (FRA)	Germany	12
16	Munich (MUC)	Germany	12
17	Stuttgart (STR)	Germany	12
18	London (LGW)	England	12
19	Vienna (VIE)	Austria	12
20	Alanya (GZP)	Turkey	12

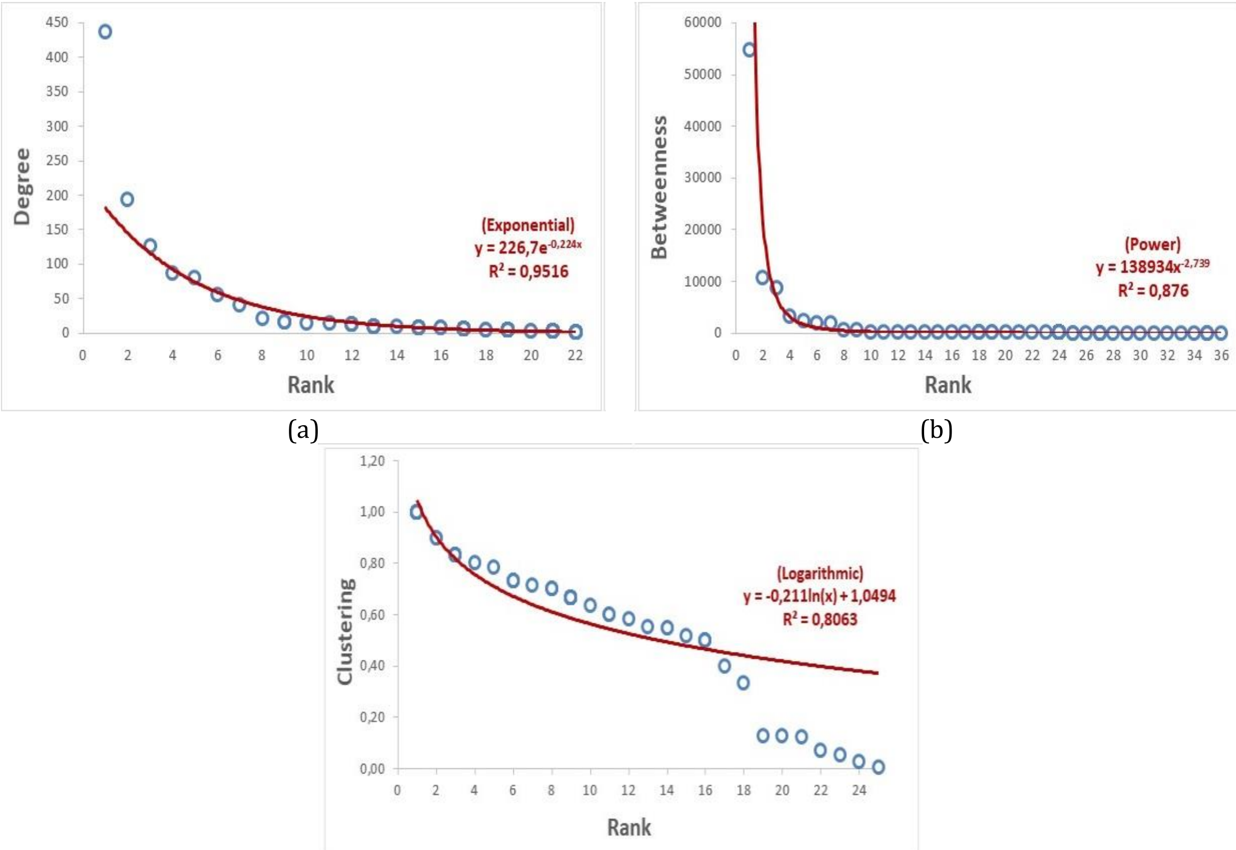
Table 3 shows the top 20 airports based on betweenness centrality. According to this table, İstanbul Atatürk Airport is ranked as the first one, followed by İstanbul Sabiha Gökçen Airport, Antalya, İzmir and Ankara. Among the top 20 airports, 11 airports are domestic flights in terms of betweenness centrality; while 9 of them are international.

Table 3. Betweenness centrality of the top 20 airports.

Rank	Airport	Country	Betweenness Centrality
1	İstanbul Atatürk Airport (IST)	Turkey	54,745.05
2	İstanbul Sabiha Gökçen Airport (SAW)	Turkey	10,561.64
3	Antalya (AYT)	Turkey	8,738.10
4	Dalaman (DLM)	Turkey	3,145.11
5	İzmir (ADB)	Turkey	2,244.64
6	Ankara (ESB)	Turkey	1,897.22
7	Bodrum (BJV)	Turkey	1,895.52
8	Brussels (BRU)	Belgium	563.14
9	Duesseldorf (DUS)	Germany	508.99
10	Trabzon (TZX)	Turkey	83.24
11	Adana (ADA)	Turkey	70.45
12	Amsterdam (AMS)	Holland	68.86
13	Dortmund (DTM)	Germany	68.50
14	Alanya (GZP)	Turkey	59.90
15	London (LGW)	England	48.11
16	Hatay (HTY)	Turkey	45.70
17	Nicosia (ECN)	Cyprus	45.28
18	Frankfurt (FRA)	Germany	44.09
19	Munich (MUC)	Germany	44.09
20	Stuttgart (STR)	Germany	44.09

3.2. Statistical distributions and correlations

When the distributions of degree and betweenness centrality indices and clustering coefficient are examined, it is seen that degree centrality index conforms to an exponential distribution with R^2 above 95%, betweenness centrality index follows power distribution with R^2 above 87% and clustering coefficient is captured by logarithmic distribution with R^2 above 80%. This means that the degree centrality values decline exponentially with one or two dominant airports. Betweenness has a power distribution; while clustering has a logarithmic distribution with the parameters indicated in Figure 2a-c.



(a) (b) (c)

Figure 2. (a) Statistical distributions of degree coefficient (b) Statistical distributions of betweenness coefficient (c) Statistical distributions of clustering coefficient.

Table 4 represents the correlation coefficients between three centrality indices and the air passenger volume of the same year. It reports that degree and betweenness centrality indices are highly correlated with the air passenger volume. As shown in Figure 3a-c, the relationship between the air passenger volume versus degree has a linear function. In addition to this, the air passenger volume decreases geometrically with its betweenness and increases geometrically with its closeness.

Table 4. Correlation between centralities and the air passenger volume.

	Air passenger volume	Degree	Closeness	Betweenness
Air passenger volume	1.000			
Degree	0.980 (0.000)	1.000		
Closeness	0.597 (0.000)	0.389 (0.000)	1.000	
Betweenness	0.929 (0.000)	0.951 (0.000)	0.360 (0.000)	1.000

p-values are given in brackets.

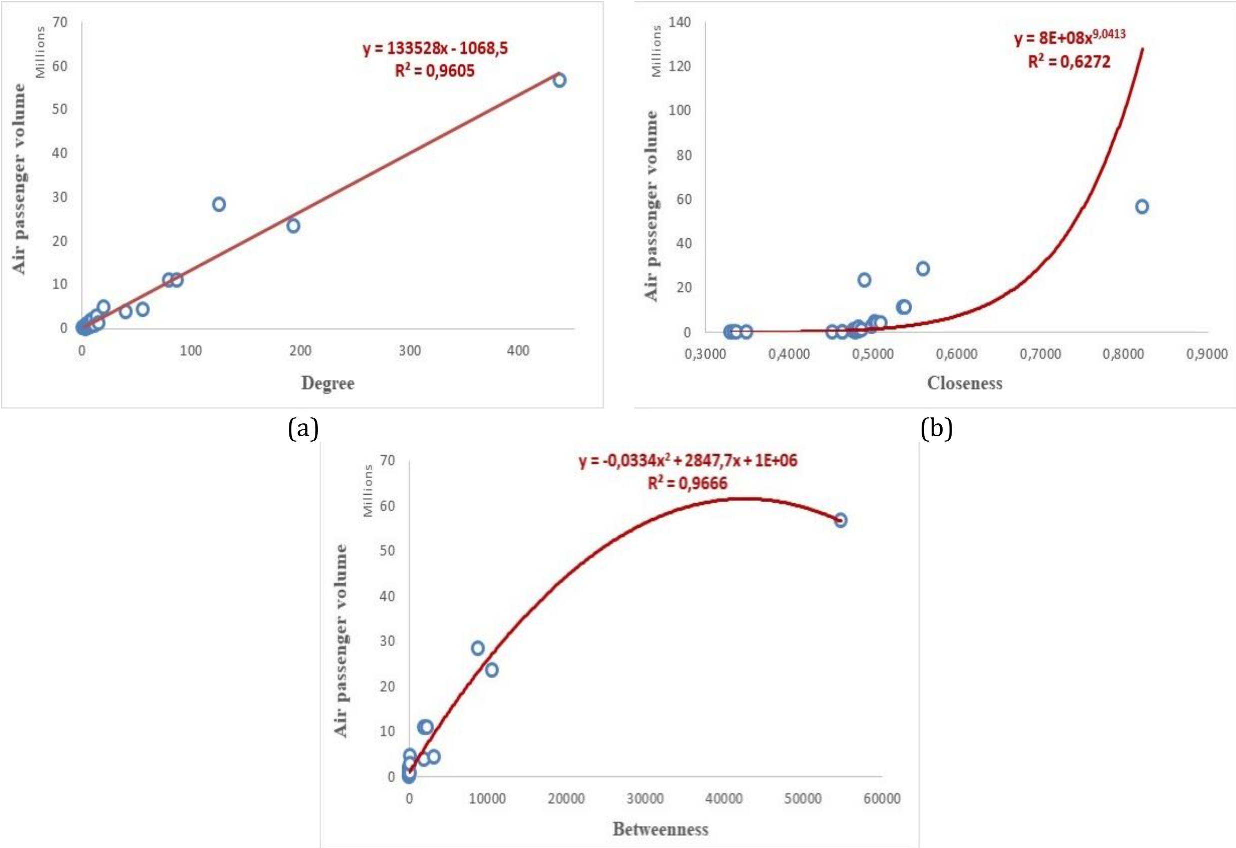


Figure 3. (a) Relationship of air passenger volume versus degree (b) Relationship of air passenger volume versus closeness (c) Relationship of air passenger volume versus betweenness

3.3. Domestic network structure

The following map (Figure 4) depicts the domestic flights in Turkey. Table 5 and Table 6 give some details about air transportation network characteristics and degree and betweenness centrality of domestic networks in Turkey, respectively. Table 5 shows that the total number of domestic airports is 38; while the total flight routes is 280. Also, the averages of in and out degree centralities are 5.03 and average degree centrality is 10.05. The network may be considered as symmetric, since the in and out degrees are highly correlated [17]. The average of all geodesic distances between airports is 27.55.

The top 10 domestic airports in terms of degree and betweenness centralities are located in Table 6. İstanbul Atatürk Airport has both the highest degree centrality with 60 and betweenness centrality with 398.33. İstanbul Sabiha Gökçen Airport follows Atatürk with 56 degree centrality and 331.33 betweenness centrality. Ankara is the third and İzmir is the fourth one in terms of their centrality values.

Figure 4. Network analysis map of the inter-city airport in Turkey.

Table 5. Turkey air transportation network characteristics.

Graph Structural Properties	
Airports	38
Flight routes	280
In degree centrality	5.03
Out degree centrality	5.03
Clustering coefficient	0.47
Average degree centrality	10.05
Average betweenness centrality	27.55

Table 6. Degree and betweenness centrality of domestic networks in Turkey.

Airport	Degree centrality	Betweenness centrality
İstanbul Atatürk Airport (IST)	60	398.33
İstanbul Sabiha Gökçen Airport (SAW)	56	331.33
Ankara (ESB)	50	277.63
İzmir (ADB)	27	30.80
Adana (ADA)	14	1.80
Antalya (AYT)	12	0.30
Trabzon (TZX)	12	0.30
Gaziantep (GZT)	8	0.30
Elazığ (EZS)	8	0.30
Diyarbakır (DIY)	8	0.30

4. Conclusion

Drawing the visual maps and the conclusions about the air transportation are beneficial for the management of economic and social assets. Besides concentrating on wide networks, in depth-analysis is required to see a specific country's air transportation structure.

This study uses social network analysis as a method to extract information about the network through a pattern of individuals and communities in Turkey. For a local perspective, 38 airports are taken as nodes and 280 routes are taken as edges; while for an international perspective, 271 airports are taken as nodes and 1,661 routes are taken as edges for the network structure analysis. Throughout the analysis, domestic connections of Turkish airports are compared with international connections. In both cases, İstanbul has two hub airports (Atatürk and Sabiha Gökçen) to connect other airports as a bridge between Asia and Europe with the highest centralities. The number of passengers using these airports are expected to increase day by day. From May 2017 to May 2018, the number of passengers increase from 23,719,468 to 27,007,651 for Atatürk Airport and 11,858,546 to 13,443,847 for Sabiha Gökçen Airport, according to the General Directorate of State Airports Authority of the Republic of Turkey.

Atatürk Airport has the highest centrality measures and the rest of the nodes are mainly not interconnected in the network. This structure shows that the network may not be resilient to any unexpected situations and it may be required more attention for policy makers of the air transportation system. The degree centrality is captured by exponential distribution with a dominant particular airport located in İstanbul. Also, both degree and betweenness centrality indices are highly correlated with the air passenger volume. İstanbul will have a great change in very near future by having a third airport in the Northern and European site of the city. After the opening of the new airport in İstanbul, it would be interesting to investigate again the evolution of this air transportation network.

This study reflects the latest air transportation structure of Turkey before the change between the Atatürk Airport and the third Airport which is still under construction. We aim to compare the results to see the differences and similarities between the current and the new airport as a future study. Also, future studies may adopt entropy based centrality measurements and weighted network analysis using the number of people or the average delay times of flights to see the traffic dynamics in the network.

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