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POPULATION DYNAMICS IN NETWORK TOPOLOGY: THE CASE OF AIR TRANSPORT NETWORK IN TURKEY

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Abstract
Networks are models of communication systems expressing the complex state of interconnection, in terms of graphs. The network paradigm has been proven powerful in modeling the complexity of real-world communication structures, such as transportation, biological, and socioeconomic systems, of the World Wide Web, etc. Among the systems of human communication, the transportation networks are of great importance for scientific research because they are related to the human need for overcoming spatial constraints to move between places and thus to communicate. Based on their capability to integrate technological evolution faster than other means of transportation, air transport networks are of particular interest in transportation research. Therefore, studying the topology of air transport networks can provide useful insights about regional and economic development and growth, for the policy and decision makers. Network measures and cartogram mapping techniques are used for the analyses. Within this context, the present paper models the air transport network of Turkey into a graph and it analyses the dynamics of this network by using an equal population cartogram. The analysis reveals the uneven geography accompanied by a west and east duality in the network topology of the air transport network of Turkey.
Keywords: Transportation networks, aviation networks, network measures, equal population cartogram

1. INTRODUCTION

Recent global technological and social evolution has revealed that the majority of communication systems, such as the World Wide Web, biological structures (e.g. brain, neural networks, etc.), systems of scientific collaboration, innovation capacity, transportation (e.g. urban traffic, subways, air traffic, marine networks, etc.), and infrastructure (e.g. water access, electricity, etc.) are ruled by high level of complexity (Barthelemy, 2011; Tsiotas and Polyzos, 2018). A modern way of modeling complex communications systems is the network paradigm (Barabasi and Albert, 1999; Diestel, 2005; Tsiotas, 2019), where the interconnected units (actors) are represented by graph nodes and their connections (relations) are expressed by links (Diestel, 2005). This modeling approach has been proven effective and popular in academia leading to a new discipline focusing on networks that emerged, so-called network science (Brandes et al., 2013).

Within the context of network science, the study of spatial networks is a major research field because space is imminent (either directly or indirectly) in communication systems (Barthelemy, 2011; Tsiotas and Polyzos, 2018). The importance of studying spatial networks becomes continuously greater due to the technological evolution and ever-increasing data availability, which has fostered researches focusing on the spatial and the geographical dimension for interpreting the complexity of the real-world communication systems (Tsiotas and Polyzos, 2015, 2018).

Air transport networks (including airports and their air traffic) are communication systems attracting attention because the aviation industry is among the most complex and fast evolving economic sectors (Tsiotas and Polyzos, 2015). In the literature, the study of air transport networks' topology has become a modern subject of research, both in worldwide (Barthelemy, 2011; Sun et al., 2017) and in regional and national level as in the case of the USA (Jia et al., 2014; Clark et al., 2018), of China (Wang et al., 2011), of India (Bagler, 2008), of Australia (Hossain and Alam, 2017), and of Greece (Tsiotas and Polyzos, 2015). These studies highlight that air transport networks are indeed complex structures which appear to evolve according to the preferential attachment procedure (Barabasi and Albert, 1999; Tsiotas and Polyzos, 2018), where already highly connected nodes (the hubs) are more likely to connect with new nodes entering the network. This state of "non-randomness" inevitably makes the study of air transport networks more crucial, taking into account that the evolution in the topology of air transport networks affects the economic growth in regional, national, and global levels (Tsiotas and Polyzos, 2015, 2018).

Analyzing air transport networks is important for better understanding the level of regional disparities because airports are large investments which directly affect the regional economies. The airport network of a region or country can provide clear insights about the connectivity and integration between the regions. However, modeling air transport networks in graphs has not yet become a common task for geographers, or urban and regional planners, and Turkey is not an exception. Turkey is a transcontinental country located in the borderline of Europe and Asia (Bakırcı, 2012; Orhan and Gerede, 2013; Duran and Erdem, 2017), it has around 82.5 million people population and a century-long history of the aviation market. With the "westernization" (i.e. compliance with the influence of the western culture) of Turkey, the sector has grown quite fast (Bakırcı, 2012). By the year 2018, the number of airports in the air transport network of Turkey (TAN) reached 55 (Erdem et al., 2019).

Within this context, the TAN is modeled into a directed weighted graph with passenger, passengers-per-flight (ppf), and cargo weights. The analysis aims at displaying the uneven geography of the air transport network for the regional and urban development dynamics in Turkey. To this aim, network analysis is conducted and, further,

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equal population cartograms are created in order to visualize and detect differential forces in the geography of TAN due to the effect of population.

The remainder of this paper is organized as follows: Section 2 presents the methodological framework and the data of the analysis, Section 3 shows and discusses the results, in Section 4 concludes the paper.

2. LITERATURE REVIEW

Air transport networks are key accelerators of the regional and national economies (Mukkala and Tervo, 2013). Basically, better infrastructure leads to less congestion and to better transport of goods, passengers, and workers, and, thus, to better accessibility to targeted markets (Banister and Berechman, 2001). The major effect of air transport networks on the regional and national economies appears in three ways. First, the air transport industry involves technology intensive and higher value-added economic structures like the fleets (e.g. aircraft, fuel trucker), the airports, and the ground handling services (Kalayci and Yanginlar, 2016). The circulation of the capital is faster in these high values added and technology-intensive sectorial components, leading to significant impulse effect on the growth of the demand to the complementary sectors. Second, the aviation industry and its supporting industries employ higher-level social and human capital (Button et al., 1999; Koroglu and Eceral, 2015). Third, the existence (or concentration) of the air transport industry in a particular location attracts the attention of the Foreign Direct Investment (FDI) which leads to additional growth (Kalayci and Yanginlar, 2016). Therefore, the air transport industry has a major impact on the regional and national economies since it provides timely and reliable transport of goods, individuals, goods, services, and knowledge (Mukkala and Tervo, 2013).

However, the impact of an air transport network on the growth of the economies is not constant along with its countries. Some regions and cities have major airports connecting all continents and hosting much more annual passengers than their population, while the traffic of other airports may be just some flights per week (ESPON, 2012). For instance, the regional distribution of airports is not constant along regions or countries like China (Wang et al., 2011), Europe (Mukkala and Tervo, 2013), USA (Goetz, 1992; Debbage and Delk, 2001), whereas major airports are heavily accumulated in particular regional hubs. Accordingly, an uneven geography is configured in the map of TAN (Erdem et al., 2019). A duality of east and west exists in the spatial distribution of the airport and the flow of passengers and goods in Turkey which the literature paid less attention.

However, many scholars paid attention to air transport networks in Turkey. In particular, Bakırcı (2012) analyzed the geographic distribution of the airports, Örkcü et al. (2016) studied the technological developments in the aviation sector, Çetin and Benk (2011) estimated the effects of deregulation of the market, Melikoglu (2017) predicted the increasing demand for jet fuels till 2020, and Saldıraner (2013) analyzed the concentration of the aviation market.

Within this context, this paper aims to build on the existing literature and to study the topology and geography of TAN, considering how population dynamics affect the network structure and functionality.

3. THE HISTORICAL BACKGROUND OF THE AIR TRANSPORT NETWORK OF TURKEY

The civil aviation activities of Turkey dates back to the establishment of the modern republic, and there are three milestones in the civil aviation history of Turkey. The first milestone is the establishment of the basic infrastructures in Istanbul and Ankara and the start of the aviation activities (Saldiraner, 2013). The second is the liberalization of the economy and reforming aviation regulations in the 1980s (Gerede, 2010). The last milestone is the implementation of the regulations for a fully liberalized aviation sector after the 2000s (Bakırcı, 2012; Saldiraner, 2013).

With the establishment of the new republic, several modernization and westernization policies were implemented including the construction of railways, the establishment of large state-owned industrial enterprises for sustaining the national growth and development (Erdem, 2016). Aviation policies were one of these westernization policies. “The future is in the skies” by the founder and the mentor of the country, Mustafa Kemal Atatürk was the motto behind the aviation policies. The aviation activities have started with the construction of two hangars and a runway in Sefaköy (Istanbul) and in Güvercinlik (Ankara). Then, the investments to the aviation infrastructures have increased in a line with the economic and technological environment of the Second World War. In 1933, the Turkish Air Lines (THY), the flag carrier of Turkey, was found as a public company to meet the domestic and international demand. Many airports were constructed in the secondary cities of Turkey to connect small and mid-size cities to the big ones. Thus, the TAN is expanded. State-owned enterprises were established to provide ground handlings and catering services. Until the 1980s, the economy and civil aviation were maintained under strict monopoly (Bakırcı, 2012; Orhan and Gerede, 2013; Saldiraner, 2013).

After the 1980s, deregulation policies were applied to the market for a more liberalized economy by lifting the import-substitution industrialization policies. With this regard, the civil aviation market was also deregulated. During this period, 34 private companies entered the market to meet the increasing demand, but 28 of them exited the market mainly due to the unstable liberalization policies. From the 1960s to the 1980s, the flow of domestic passengers and cargo has increased almost 5 times, as it is shown in Table 2. The THY improved its capacity and service quality targeting the international market. The TAN has expanded to eastern, western, northern and southern Turkey. Besides the secondary airports, several new airports were established in smaller cities. In this period, the number of airports in Turkey has reached 40 (Bakırcı, 2012).

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TABLE 2 - AIRLINE PASSENGER AND CARGO TRANSPORT FLOWS IN TURKEY, FOR THE PERIOD 1960–2018

			Passenger		Cargo	
Year	**Population**	**Total**	***Domestic***	***International***	***Domestic***	***International***
1960	27,754,820	713,217	528,846	184,371	13,002	4,696
1970	35,605,176	2,679,139	1,661,890	1,017,249	44,039	19,790
1980	44,736,957	3,458,165	1,621,998	1,836,167	75,443	43,211
1990	56,473,035	13,629,965	5,347,723	8,282,242	301,403	201,854
2000	67,803,927	34,972,534	13,339,039	21,633,495	796,627	570,271
2010	73,722,988	102,705,805	50,516,654	52,189,151	2,023,221	1,467,350
2018	82,003,882	210,189,945	112,758,617	97,431,328	3,855,231	2,969,206

Source: TUIK (2010); GDSAA (2018)

After the millennium, terminating the policies that provide privileges to THY has helped the liberalization of the aviation market in Turkey. In this period, several low-cost-carrier (LCC) companies have entered the market to meet both the domestic and international in competition with the THY. “Low fares with low cost and a low-profit-margin” was the main strategy of these companies targeting middle-income passengers. In 2008, the THY established the “AnadoluJet” operator, mainly to meet meeting domestic demand and to compete with the LCC private carriers. Ankara was selected as the operational hub of AnadoluJet since it is the capital city of Turkey and it is close to the geographic center of Turkey. AnadoluJet entered the market with the lowest ticket price strategy and the motto that “Every Turkish citizen will board at least once”. Several airports were established by the public-private partnership with the build-operate-transfer model (Tam, 1999) in this period. For the year 2018, the number of airports increased to 55. The number of domestic passengers has increased more than 7 times between the years 2000 and 2018, making the ratio of passengers to the population greater than 1 first time in Turkish aviation history (Table 2). There were a total of 2 public and 5 private companies operating in the domestic market in this period (Orhan and Gerede, 2013).

4. METHODOLOGY AND DATA

The analysis of the population dynamics in the network topology of TAN is based on complex network analysis (Barabasi and Albert, 1999; Barthelemy, 2011; Tsiotas and Polyzos, 2018) and analysis of equal population cartogram. On the one hand, the graph-theoretic measures of network topology are computed for measuring aspects of the network topology of TAN, which consists of three layers constructed on flight (layer G_α), passenger (layer G_β) and cargo (layer G_γ) flows between airports. Complex network measures capture different aspects of network topology, either in global or in local (node) scale and thus their overall consideration suggests an approximation of the network topology (Tsiotas and Polyzos, 2018). On the second hand, the equal population cartogram analysis is applied to detect how the spatial distribution of the population in Turkey affects the structure and functionality of TAN.

In particular, the graph-model of TAN is modeled in the L-space representation (see Barthelemy, 2011) into a directed, multiplex, weighted graph $\mathcal{M}(\mathcal{G},\mathcal{C})$, which is composed by three different layers $\mathcal{G}=\{G_\alpha,G_\beta,G_\gamma\}$, with no interlayer connections ($\mathcal{C}$=Ø) between them. All layers $G_α$={$V_α$,$E_α$}, $G_β$={$V_β$,$E_β$}, and $G_γ$={$V_γ$,$E_γ$} of the TAN are produced on the same set of nodes, namely $V_α$=$V_β$=$V_γ$=V, which represent the airports that were operating in Turkey at the year 2017. However, the links in each layer represent different types of connections. Particularly, $E_α$ expresses the annual passenger flows, $E_β$ the ppf, and $E_γ$ expresses the annual cargo flows between the airports (nodes) of the TAN.

For the network analysis of TAN, a set of fundamental measures of network topology is computed for each layer ($E_α$, $E_β$, and $E_γ$) as it is shown in Table 1.

TABLE 1 - MEASURES OF NETWORK TOPOLOGY CONSIDERED IN THE ANALYSIS OF TAN.

Measure	Symbol	Description	Reference
Average Degree	$\langle k \rangle$	The mean value of the node degrees. It measures how important is a node in the network in terms of connectivity.	Diestel (2005)
Clustering coefficient	C	The local clustering coefficient expresses the probability of meeting linked neighbours around a node, which is equivalent to the number of the node's connected neighbours E(i) (i.e. the number of triangles), divided by the number of the total triplets shaped by this node, which equals to $k_i(k_i–1)$. It generally measures the tendency of nodes to cluster with their neighbors. The global clustering coefficient counts the total number of triangles relatively to the total number of triplets in the network.	Barthelemy (2011)
Average clustering coefficient	$\langle C \rangle$	The average clustering coefficient of the network nodes.	Barthelemy (2011)
Modularity	Q	Objective function expressing the potential of a network to be subdivided into communities. In its mathematical formula, it computes the label of the community of a node and the difference of the actual minus the expected number of edges falling between a particular pair of vertices.	Blondel et al. (2008); Fortunato (2010)
Average path length	$\langle k \rangle$	The average length of the network shortest paths. It is considered as a measure of the communication efficiency in a network.	Barthelemy (2011)
Graph density	ρ	The fraction of the existing connections of the graph to the number of the possible connections. It measures whether a graph is dense or sparse.	Diestel (2005)

The analysis of the multiplex TAN is based on the population diffusion cartogram, which is constructed for each layer ($G_α$, $G_β$, and $G_γ$). In mathematical terms, the construction of a flat 2-dimensional (2D) cartogram concerns finding a transformation r→T(r) of one plane to another plane, so that the Jacobian ∂(Tx,Ty)/∂(x,y) of the transformation to be proportional to some specified population density ρ(r), according to the relation (Gastner and Newman, 2004):

$$\frac{\partial(Tx,Ty)}{\partial(x,y)}=\frac{\partial T_x}{\partial x}\cdot\frac{\partial T_x}{\partial x}=\frac{\partial T_x}{\partial y}\cdot\frac{\partial T_y}{\partial x}=\frac{\rho(r)}{\bar{\rho}} \quad (1),$$

where $\bar{\rho}$ is the average population density computed over the area to be mapped.

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The diffusion considered for the construction of cartograms is extracted from Gastner and Newman (2004) according to the relation:

$$\mathbf{J} = -\nabla \rho \tag{2}$$

which implies that the diffusion follows the gradient of the density field and particularly that the flow is always directed from high density to low-density regions and thus that the flow will be faster when the gradient is steeper. Another attribute of the cartogram is that the diffusion population is locally being conserved, according to the relation (Gastner and Newman, 2004):

$$\nabla \mathbf{J} + \frac{\partial \rho}{\partial t} = 0 \qquad (3),$$

where t is the time of diffusion, which is implemented with velocity $\mathbf{v}(\mathbf{r},t) = -\frac{\nabla \rho}{\rho}$ and density $\rho(\mathbf{r},t)$, at position $\mathbf{r}$.

Overall, the calculation of the cartogram involves solving the equation (Gastner and Newman, 2004):

$$\nabla^2 \rho - \frac{\partial \rho}{\partial t} = 0 \qquad (4),$$

for $\rho(\mathbf{r},t)$, considering the initial condition in which ρ equals to a region's given population density and afterward by calculating the corresponding velocity field $\mathbf{v}(\mathbf{r},t)$.

The population diffusion cartogram algorithm of Gastner and Newman (2004) ensures that the population diffuses until it is uniform anywhere within the box enclosing the map, except for the statistical fluctuations. The cartogram is constructed by moving all boundaries on the map so that the net flow passing through them becomes zero at all times during the diffusion process. Generally, a cartogram is produced by the distortion of a source map in accordance with the distribution of a thematic variable (e.g. population, GDP, etc.), provided that the distorted and the source maps are isomorphic. Using a cartogram for the study of a thematic variable generally allows extracting information about how this variable is being distributed along the area of the map. In the case of studying interconnection systems, such as networks (e.g. the TAN), a cartogram illustrates the invisible "pressures" which the control variable applies to the system and therefore it illustrates how the control variable affects the conduct of communication.

Finally, the data is available for the analysis are extracted from the Turkish General Directorate of State Airports Authority (GDSAA, 2018) and regard registrations of passenger, flights, and cargo flows, for the year 2017.

5. RESULTS AND DISCUSSIONS

The analysis of TAN aims to reveal the dynamics of this air transport network for regional and urban development. At first, the fundamental measures of network topology are computed for the multiplex TAN, as it is shown in Table 3. Next, the topological layouts of each layer (G_α, G_β, and G_γ) are created. Finally, the effects of population on the network's topology, as these are being captured by diffusion population cartograms are studied. All three layers G_α, G_β, and G_γ appear in Fig.1 a cellular topology, with the main core of hub airports being the same for all three cases of passenger and cargo flows.

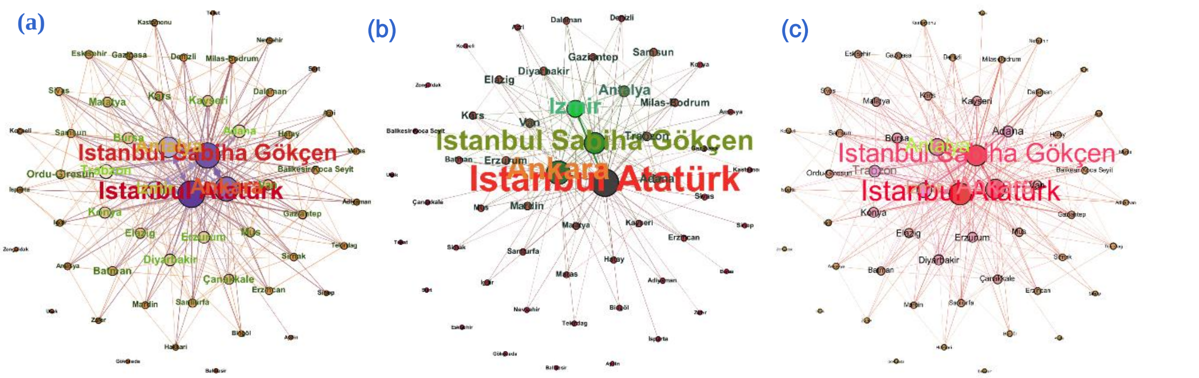

FIGURE 1 - THE TOPOLOGY OF THE (DIRECTED) TURKISH AIR TRANSPORT NETWORK (TAN) WITH (A) PASSENGER, (B) PASSENGER PER FLIGHTS (PPF), AND (C) CARGO FLOWS WEIGHTS. NETWORKS ARE EMBEDDED IN THE FRUCHTERMAN REINGOLD LAYOUT (BASTIAN ET AL., 2009) (DATA FOR THE YEAR 2017).

The Fruchterman Reingold topological layouts (Bastian et al., 2009) of the multiplex TAN are shown in Fig.1. The layers G_α and G_β have m_α=m_β=549 links, whereas G_γ has m_γ=263 links. In comparison with the air transport networks of Australia, USA, India, and China, the size (n,m) of TAN appears relatively low.

However, the average clustering coefficient (measures the likelihood of meeting connected neighbors in a given node) of the multiplex TAN has a value of 0.60 (Table 3), which is comparable with 0.66 of India (Bagler, 2008), 0.73 of the USA (Wang et al., 2011), 0.69 of China (Wang et al., 2011), and 0.50 of Australia (Barros, 2008). Therefore, the topology of TAN appears more effective in terms of serving air transport by developing air transport clusters almost along with the entire country.

TABLE 3 - NETWORK MEASURES OF THE MULTIPLEX TAN

Layer	*n* Num. of nodes	*m* Num. of nodes	*k* Average degree	*C* Clustering coefficient	<C> Av. Clust. coefficient	*Q* Modularity	<l> Av. path length	*ρ* Graph density
Passengers (G_α)	55	549	9.982	0.432	0.608	0.054	1.802	0.185
PPF (G_β)	55	549	9.982	0.432	0.608	0.143	1.802	1.185
Cargo(G_γ)	55	269	4.891	0.270	0.69	0.02	1.951	0.091

Despite the good clustering of TAN, the dominating airports (hubs) appear to be mainly located in the western part of Turkey. Table 3 shows that the layers G_α and G_β have bigger clustering coefficient (C) than the G_γ.

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Namely, the TAN appears more clustered in serving passenger ($G_α$, $G_β$) than cargo flows, implying that passenger air transport is more integrated than the cargo at the global level. Therefore, cargo transport is conducted through air transport more in the central (core) routes, and less in the peripheral routes, in comparison with passenger transport.

This implies that cargo is transported in periphery more by using alternative to air transport modes (e.g. by road transport), in comparison to the case of passengers' transportation. However, the picture that we get for the average clustering coefficient (<C>) is completely opposite. That is to say, at the local level (i.e. in the level of the neighborhood) the TAN appears less clustered in serving passenger ($G_α$, $G_β$) than cargo flows, implying that cargo is more integrated than the passenger transport at the neighborhood level.

Thus air transport is more preferable for transporting cargo locally than passengers. That is to say, people are transported in local clusters more by using alternative to air transport modes. Next, the scores of modularity (Q) show that generally, TAN does not have a high tendency to be divided into communities. Finally, according to the average path length, TAN has satisfactorily effectiveness because two places in this network are accessible through almost 2 flights on average.

At the next step, equal population cartograms for the multiplex TAN are being studied. As previously mentioned, an equal population cartogram is a tool for displaying the distortion of the map in accordance with the uneven distribution of the variable (Gastner and Newman, 2004). For all the three layers ($G_α$, $G_β$, and $G_γ$), the geographical map (cases a) and their equal population cartograms (cases b) are shown in Fig.2, 3, and 4.

The black lines represent the volume of flows (passenger, ppf, and cargo) between the airports, whereas the red circles are drawn proportionally to node degree of the airports (bigger circles correspond to higher node degree and thus higher airport connectivity), for each layer. The line thickness expresses the intensity of flows between airports. These maps reveal significant results that are consistent with the literature (Erdem et al., 2019; Orhan and Gerede, 2013).

In particular, Fig.2a ($G_α$) shows a distinct hierarchy among the TAN (major, secondary, and minor) airports and a distinct geographical concentration to the western part of Turkey. Airports with degree ranging between 40-91 connections are Atatürk, Sabiha Gökçen, İzmir, Ankara, and Antalya, are mainly located at the west part of the country. A similar to the node concentration is observed for the number and the weights (lines' intensity) of the edges, also. Passenger flows between these airports ranges between 1 and 3.4 million. Accordingly, the major airports of the TANare concentrated on western Turkey, while, the secondary airports (the passenger volume of which ranges between 0.3 and 1 million) are concentrated on the eastern part of the country. The minor airports (the passenger volume of which are under 0.3 million) are distributed between the major and secondary airports, both in the west and east Turkey.

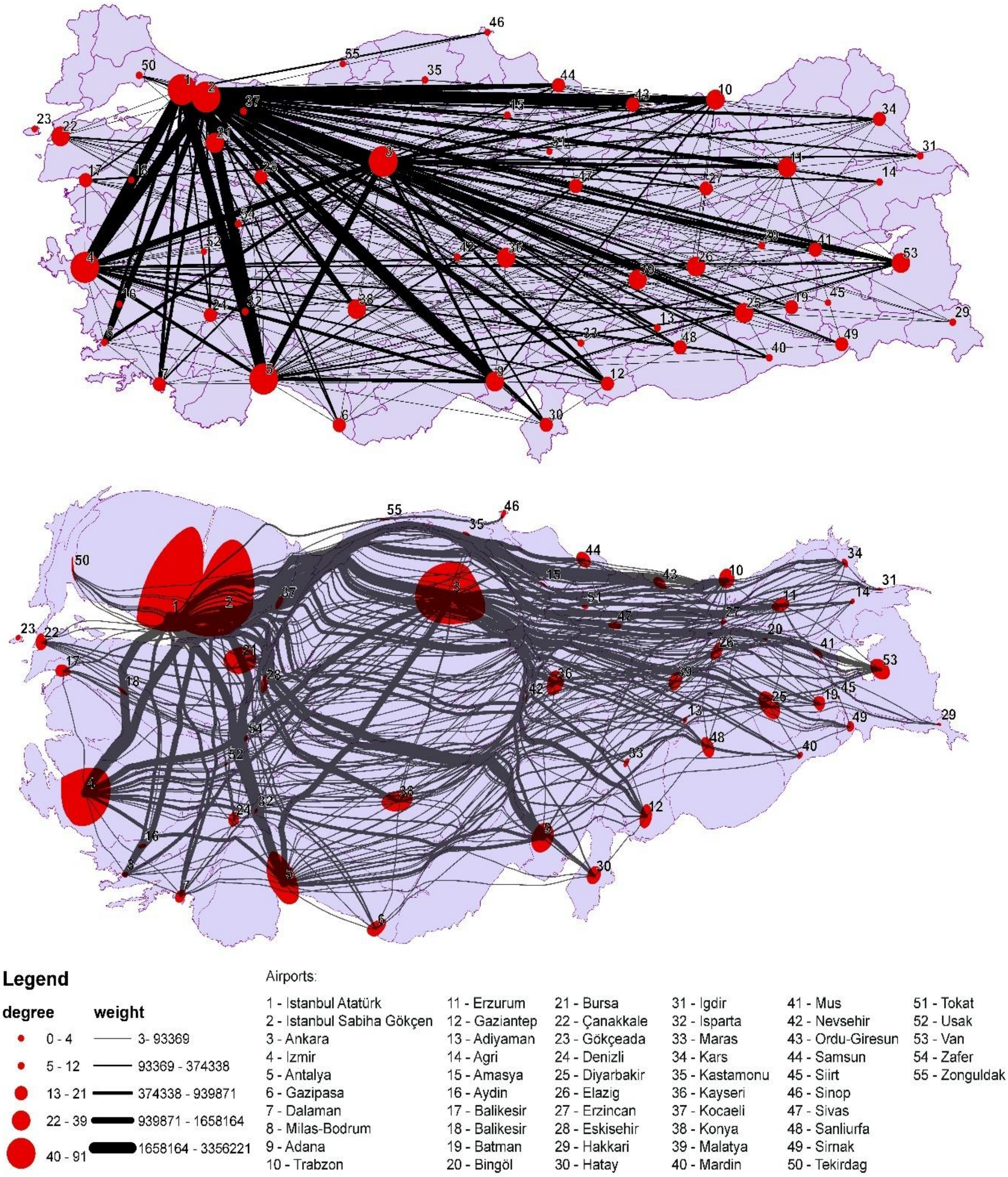

FIGURE 2 - (A/TOP) THE GEOGRAPHICAL MAP OF TAN WITH PASSENGER-FLOW WEIGHTS
(B/BOTTOM) A POPULATION DIFFUSION CARTOGRAM OF THE TAN WITH PASSENGER-FLOW WEIGHTS
(DATA FROM THE YEAR 2017)

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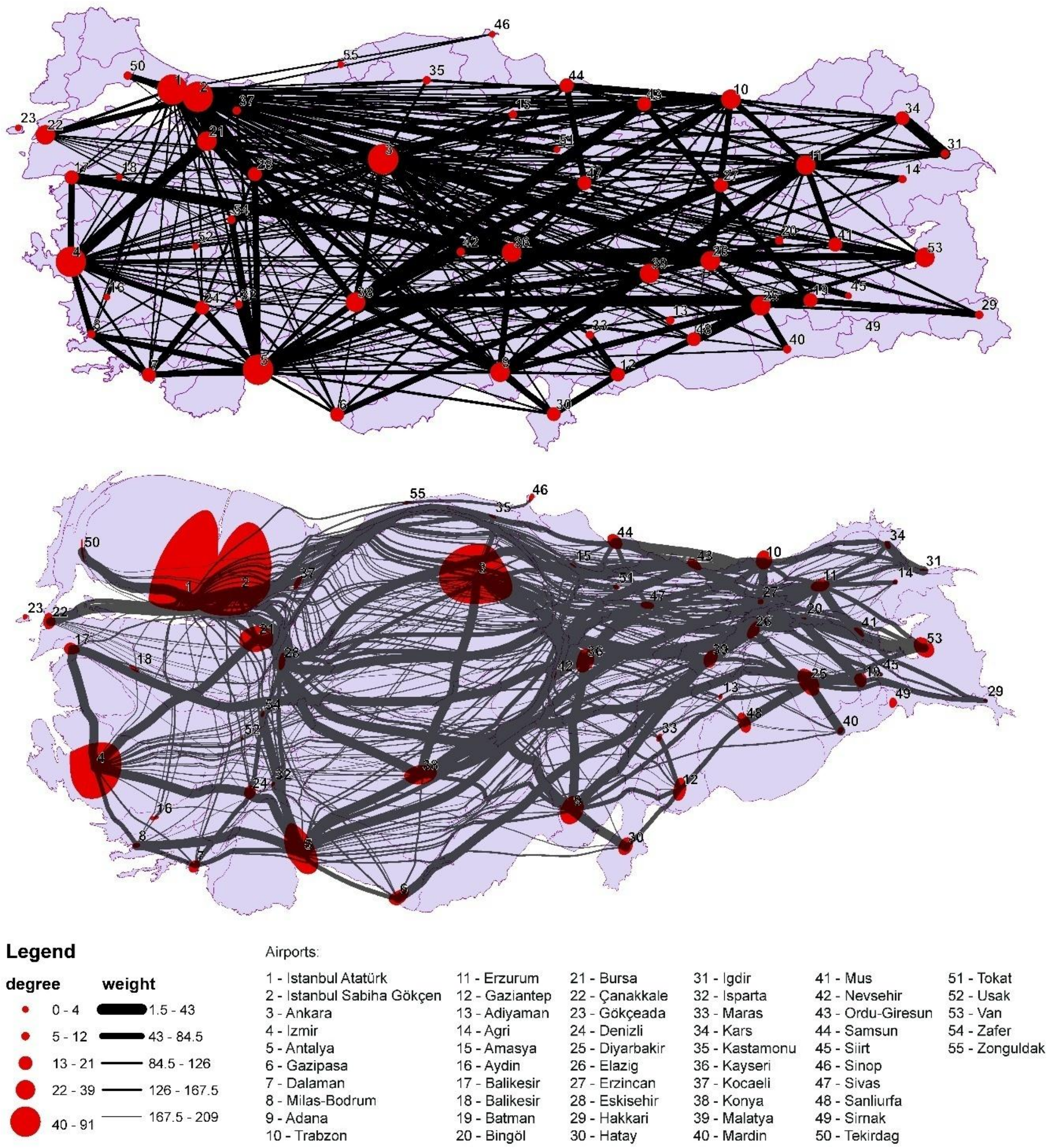

FIGURE 3 - (A/TOP) THE GEOGRAPHICAL MAP OF THE TAN WITH FLIGHT-FLOW WEIGHTS
(B/BOTTOM) A POPULATION DIFFUSION CARTOGRAM OF THE TAN WITH FLIGHT-FLOW WEIGHTS (DATA FROM THE YEAR 2017)
FOR BETTER DISPLAYING THE PASSENGER PER FLIGHT (PPF), THE THICKNESS OF THE EDGES IS REVERSED AS LOW TO HIGH

The Fig.2b (G_α) shows the geo-spatiality of the TAN on equal population cartogram, in order to display the regional per-person passenger disparities among the TAN airports. This distorted map reveals that the regions in western Turkey have more population concentration than those in eastern Turkey. This observation complies with the expanded distortion pattern shown for regions located in western Turkey, while regions located in eastern Turkey appear a shrinking pattern. Additionally, nodes and links are also distorted in accordance with the population's spatial distribution. This distorted picture contributes to sufficient understand the spatiality of the passenger disparities among the air transport network of Turkey's airports. In particular, we observe distortion among the nodes that are located in western Turkey and at a similar degree. The highest distortion is observed for the airports of Istanbul, followed by the airports of Ankara, Izmir, and Antalya. This implies that the population is quite concentrated in Istanbul, although the city has two airports (the Atatürk and Sabiha Gökçen), these are not sufficient for serving the demand generated from such population. According to Airport Council International Europe (ACIE, 2015), the Atatürk airport (which is among the top 10 airports in the world) is ranked as the 3rd airport with the longest delay in Europe, for the year 2015.

Next, the map in Fig.3 ($G_β$) illustrates that the most populated cities, for which the per-person-flight (ppf) is higher, have an expanding distortion, whereas, the minor cities appear to be shrinking. The expanding distortion expresses the manipulation of the map by resizing the areas according to the higher population of the regional hubs, whereas the shrinking areas show the backless populous regions (Dorling, 2012). The Fig.3 ($G_β$) shows that the thicker lines are distributed throughout both the west and east part of the country. This complies with the finding of Orhan and Gerede (2013) stating that passengers prefer air transport for covering time-distances longer than 6 hours. This finding is also consistent with the results of (global) clustering coefficient shown in Table 3, implying that passengers prefer to use air transport for long distances. Turkey is a big country, and it takes about 36 hours to travel by road from the west to the east side. This is why the links between the smaller airports in eastern Turkey and the major western airports like Atatürk, Sabiha Gökçen, and İzmir are thinner.

Finally, Fig.4 ($G_γ$) shows the geospatial and cartogram maps of the TAN in terms of cargo flows. As it can be observed from the intensity of the edge weights, the transport of cargo through air transportation is quite limited in Turkey. This complies with the previous (network analysis) finding that cargo is less integrated than passenger transport in Turkey at the global level. In particular, the majority of the aviation sector in Turkey heavily depends on the transportation of passengers. Accordingly, the flow of the cargo is mainly between the major airports including Atatürk, Sabiha Gökçen, Ankara, İzmir, and Antalya. Additionally, according to the intensity of their edge weights, the Gaziantep and the Trabzon airports seem to belong to this major club, since the lines of these airports with the airports in Istanbul are evidently thicker. Similar to the previous maps, we observe a greater concentration on western Turkey, but the edge intensity appears relatively thinner in the east, especially when compared with the passenger flow maps. Moreover, comparing the maps of layers $G_α$ and $G_γ$, we observe that degree sizing in eastern Turkey for cargo flows ($G_γ$) is narrower. Still, the hierarchy of the airports of Turkey regarding the flow of passenger and cargo is also quite obvious as shown in Fig.4. The major, secondary, and the minor airports of cargo flows ($G_γ$) appear to follow a similar state of hierarchy with this in the layer ($G_β$). The degree centrality of the airports transporting the major load of freights ranges between 37 and 72. Therefore, the degree centrality of TAN for cargo flows appears lower than the flow of passengers.

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Overall, studying the topology of air transport networks is an important task capable to provide insights about the presence of regional disparities, provided that unbalanced regional disparities lead to less cohesion and stability in the economy of countries (Romer, 1990). As evident in the previous analysis, the TAN's topology on the passenger (G_α , Fig.2), ppf (G_β, Fig.3), and cargo (G_γ, Fig.4) flow indicate that the western part of Turkey is more connected than the eastern part, where the major airports of Istanbul, Ankara, Izmir, and Antalya are located. The cities of these airports possess 33% of the national population, 71% of the domestic air traffic, giving insight to regional disparities.

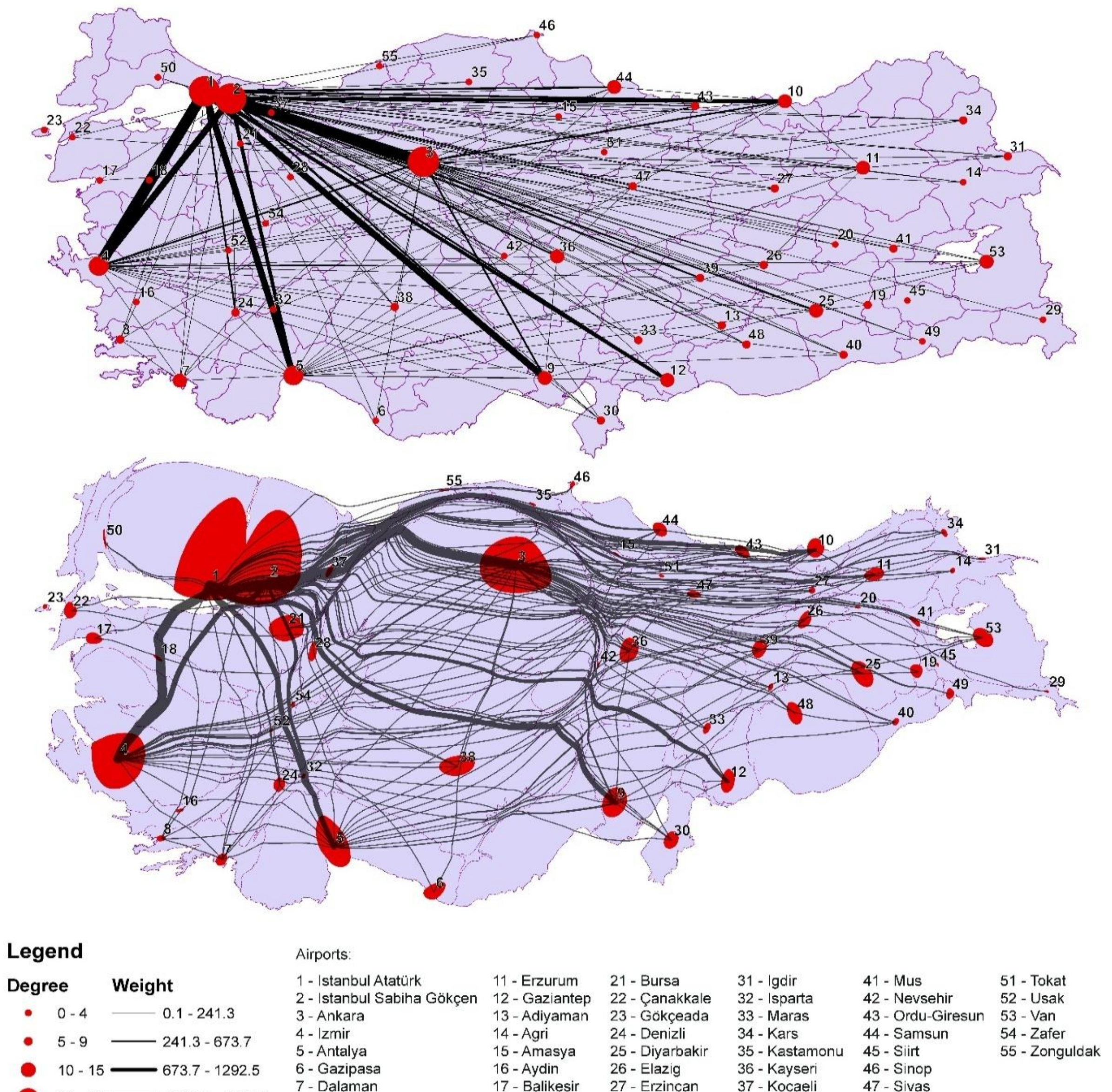

FIGURE 4 - (A/TOP) THE GEOGRAPHICAL MAP OF TAN WITH CARGO-FLOW WEIGHTS
(B/BOTTOM) A POPULATION DIFFUSION CARTOGRAM OF THE TAN WITH CARGO-FLOW WEIGHTS
(DATA FROM THE YEAR 2017).

5. CONCLUSIONS

Analyzing regional disparities is quite important for developing stable regional economies and cohesion. In this paper, the air transport network of Turkey (TAN) is modeled into a multiplex graph and the dynamics of this network is analyzed by using measures of network topology and an equal population cartogram approach. Analyzing the airport networks of countries can provide insights about the regional disparities of the countries, both at the national and regional levels. With this regard, this paper reports a quite clear duality between the west and the east of the air transport network of Turkey. The airports in western Turkey are the major airports of the air transport network of Turkey, which also host greater volumes of passenger and cargo flows. The western major airports are more connected, even they are geographically closer to each other. Eastern airports are connected with western major airports. The volume of passengers-per-flight is lower for the airports that are closer both in western and eastern Turkey. Although there are some links between the major and secondary airports, direct links between the secondary airports are quite limited. Governments, decision-makers, planners, and geographers should undoutedly pay more attention to the uneven geography of airports and regional aviation policies.

REFERENCES

ACI (2015). Airports Council International Europe, TOP-30 European Airports 2015, available at https://www.aci-europe.org/ policy/ position-papers.html? view= group&group=1&id=11 [accessed: 22.04.2018].

Bagler, G. (2008). Analysis of the airport network of India as a complex weighted network. *Physica A: Statistical Mechanics and its Applications*, 387(12), 2972-2980.

Bakırcı, M. (2012). Ulaşım coğrafyası açısından Türkiye'de havayolu ulaşımının tarihsel gelişimi ve mevcut yapısı. Marmara Coğrafya Dergisi Sayı: 25, Ocak - 2012, s. 340 – 377 [in Turkish].

Banister, D., & Berechman, Y. (2001). Transport investment and the promotion of economic growth. Journal of transport geography, 9(3), 209-218.

Barabasi, A. L., & Albert, R. (1999). Emergence of scaling in random networks. Science, 286(5439), 509-512.

Barros, C. P. (2008). Airports in Argentina: Technical efficiency in the context of an economic crisis. *Journal of Air Transport Management*, 14(6), 315-319.

Barthelemy, M. (2011). Spatial networks. Physics Reports, 499(1-3), 1-101.

Bastian M., Heymann S., & Jacomy M. (2009). Gephi: An open source software for exploring and manipulating networks. *Proceedings of the Third International ICWSM Conference* (AAAI Press, Menlo Park, CA), 361–362.

Blondel, V., Guillaume, J.-L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. Journal of Statistical *Mechanics*. 10, P10008.

Brandes, U., Robins, G., McCranie, A., & Wasserman, S. (2013). What is network science? *Network Science*, 1, 1– 15.

Button, K., Lall, S., Stough, R., & Trice, M., (1999). High-technology employment and hub airports. *Journal of Air Transport Management,* 5 53–59

Çetin, T., & Benk, S. (2011). *Regulation, deregulation, and competition in the Turkish airline industry. In The Political Economy of Regulation in Turkey* (pp. 193-214). Springer, New York, NY.

Clark, K. L., Bhatia, U., Kodra, E. A., & Ganguly, A. R. (2018). Resilience of the US National Airspace System Airport Network. IEEE Transactions on Intelligent Transportation Systems.

Debbage K. G., & Delk, D. (2001). The geography of air passenger volume and local employment patterns by US metropolitan core area: 1973–1996. *Journal of Air Transport Management,* 7 159–167

Diestel, R. (2005). Graph Theory, Third ed. Springer–Verlag Publications, Heidelberg, Germany.

Dorling, D. (2012). The Visualization of Spatial Social Structure. Chichester: Wiley.

Duran, H. E., & Erdem, U. (2017). Regional inequality and international trade in Turkey: A dynamic spatial panel approach. *A| Z ITU Journal of the Faculty of Architecture*, 14(3), 25-39.

Erdem, U. (2016). Regional human capital distribution and disparities in Turkey. Review of *Urban & Regional Development Studies*, 28(1), 16-31.

Erdem, U., Cubukcu, M. K., & Tsiotas, D. (2019). Mapping the topology of the air transport network in Turkey. *Environment and Planning A: Economy and Space*. https://doi.org/10.1177/0308518X19848753

ESPON (2012). *Airports as drivers of economic success in peripheral regions. Targeted Analysis 2013/2/17*. Interim report, ESPON, Luxembourg

Fortunato, S. (2010). Community detection in graphs. *Physics Reports*. 486, 75–174.

Gastner, M. T., & Newman, M. E. (2004). Diffusion-based method for producing density-equalizing maps. *Proceedings of the National Academy of Sciences*, 101(20), 7499-7504.

GDSAA. (2018). *General Directorate of State Airports Authority of Turkey, Annual next and previous airports pairs of domestic flights, passengers, and cargo traffic*, Ankara:Turkey.

Gerede, E. (2010). The evolution of Turkish Air Transport Industry: Significant Developments and the Impacts of 1983 Liberazation. *Journal of Management and Economics*, 17(2), 63-91.

Goetz A.R. (1992). Air passenger transportation and growth in the U.S. urban system 1950–1987, *Growth and Change* 23 218-242

Hossain, M. M., & Alam, S. (2017). A complex network approach towards modeling and analysis of the Australian Airport Network. *Journal of Air Transport Management*, 60, 1-9.

Jia, T., Qin, K., & Shan, J. (2014). An exploratory analysis on the evolution of the US airport network. *Physica A: Statistical Mechanics and its Applications*, 413, 266-279.

Kalayci, S., & Yanginlar, G. (2016). The Effects of Economic Growth and Foreign Direct Investment on Air Transportation: Evidence from Turkey. *International Business Research*, 9(3), 154-162.

Koroglu, B. A., & Eceral, T. O. (2015). Human capital and innovation capacity of firms in defense and aviation industry in Ankara. *Procedia-Social and Behavioral Sciences*, 195, 1583-1592.

Melikoglu, M. (2017). Modelling and forecasting the demand for jet fuel and bio-based jet fuel in Turkey till 2023. *Sustainable Energy Technologies and Assessments*, 19, 17-23.

Mukkala, K., & Tervo, H. (2013). Air transportation and regional growth: which way does the causality run? *Environment and Planning A*, 45(6), 1508-1520.

Orhan, G., & Gerede, E. (2013). A study of the strategic responses of Turkish airline companies to the deregulation in Turkey. *Journal of Management Research*, 5(4), 34-63.

Örkcü, H. H., Balıkçı, C., Dogan, M. I., & Genç, A. (2016). An evaluation of the operational efficiency of Turkish airports using data envelopment analysis and the Malmquist productivity index: 2009–2014 case. *Transport Policy*, 48, 92-104.

Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, Part 2), S71- S102.

Saldiraner, Y. (2013). Airport master planning in Turkey; planning and development problems and proposals. *Journal of Air Transport Management*, 32,71-77.

Saldıraner, Y. (2013). Airport Ownership and Management in European Union Countries, BOT Applications in Turkey, and Suggestions for Turkey. *International Journal of Economics, Finance and Management Sciences*, 61-67.

Sun, X., Gollnick, V., & Wandelt, S. (2017). Robustness analysis metrics for worldwide airport network: A comprehensive study. *Chinese Journal of Aeronautics*, 30(2), 500-512.

Tam, C. (1999). Build-operate-transfer model for infrastructure developments in Asia: reasons for successes and failures. *International journal of project management*, 17(6), 377-382.

Tsiotas D., & Polyzos S. (2015). Decomposing multilayer transportation networks using complex network analysis: A case study for the Greek aviation network. *Journal of Complex Networks*, 3(4), 642-670.

Tsiotas D., & Polyzos S. (2018). The complexity in the study of spatial networks: An epistemological approach. Networks and Spatial Economics, 18(1), 1–32.

Tsiotas, D. (2019) Detecting different topologies immanent in scale-free networks with the same degree distribution, *Proceedings of the National Academy of Sciences of the United States of America (PNAS),* 116(14), pp.6701-6706.

TÜİK. (2010). *Türkiye İstatistik Kurumi Başkanliği, İstatistik Göstergeler 1923–2009.* Türkiye İstatistik Kurumu Yayını. Ankara, http://www.tuik.gov.tr/Kitap.do?metod=KitapDetay&KT_ID=0&KITAP_ID=160 [accessed: 25/4/19].

Wang, J., Mo, H., Wang, F., & Jin, F. (2011). Exploring the network structure and nodal centrality of China's air transport network: A complex network approach. *Journal of Transport Geography*, 19(4), 712-721.