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Comparative evaluation of the Brazilian air transport system centrality

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ABSTRACT

This work seeks to analyze the centrality of the Brazilian airport commercial system and compare flights data of 2015 and 2019. This paper is an extension and updated study from article presented at VII RIDITA (Pereira et al., 2019). We evaluated the Brazilian airport system by the results of layer centrality and h-centrality. These methodologies of centrality, unlike other traditional methods in graphs theory, try to evaluate the comprehensiveness of each vertex (in the case of the airport) and the influence on the others in the network. The results show the main characteristic of the Brazilian airport system regarding the concentration of the operation in regions and airports. Central airports demand greater attention from the agents in several operational fields (maintenance, traffic control, mobility, etc.) to raise the quality of the system.

1. Introduction

The network analysis based on centrality studies allow performance evaluation and identification of main points considering their interaction and the importance among the network. Aspects of intensity of the edge relation and also network weakness are better explored in centrality studies of graph theory.

The centrality studies on air transports system leverages the analysis, more than just passengers' number of cargo tonnage transportation to rank, since the assessment presents the main point of a network. The main points, in this case the airports, mean the hubs which influence the connections and even the weakness in the network.

Centralities studies on airport network involve assessment of hub center locations with high connectivity and demand. The variable used here of number of flights allows the definitions of hub center points by air routes analysis.

The air transport industry performs one third, in value, of global cargo trade. On the other hand, in Brazil, this sector is responsible for only 1.4% of the country's GDP (IATA, 2016). In this industry, airports play a strategic role to both government and private companies (Bel and Fageda, 2008; Doganis, 1992).

Indeed, the availability of Brazilian airports and the coverage of domestic air network are adequate, with a distribution that mirrors population concentration, according to McKinsey & Company (2010). There are approximately 2498 airports (including landing areas) in Brazil, i.e., the second largest number of airports in the world, only behind the United States.

However, only 131 of them are commercially explored, and 34 airports are used for international connections in 2019. Moreover, only three, of all commercial airports, are rated among the top 100 in the world (IATA, 2016). In fact, the quality of airport infrastructure in Brazil is ranked by executives in 19th place, out of 23 countries from Latin America and Caribbean, and 112th globally (IATA, 2016). From Wolff et al. (2019) we highlight air transport used as mode of freight has less time of travel and greater security, but at a high cost which is suitable to high added value products.

In terms of historical data, Fig. 1 shows a growth over the past year, regarding the number of flights, as well as the proportion of the domestic and the international market, based on data from the National Civil Aviation Agency – ANAC (in Portuguese, Agência Nacional de Aviação Civil (ANAC, 2019).

We could observe that the number of flights in 2018 raised backed near data from 2010, although its peak occurred in 2012 and since them was decreasing. We highlight this is a sector with great importance for Brazilian economics (Pereira et al., 2017). Moreover, the proportion of international flights grew considerably. This paper used the data from 2015, which is a year after the 2014 FIFA World Cup in Brazil and before 2016 Olympic Games in Rio de Janeiro/RJ, to compare with 2019, which is a year when the company Avianca stopped their operation after 12% passengers market share in 2018.

The aim of the paper is to evaluate the Brazilian air network using the results from measure of h-centrality (Pereira and Soares De Mello, 2020) detailed in Section 2.3 and layer centrality (Brandao et al., 2020) detailed in Section 2.4. These results herein show a comparative period

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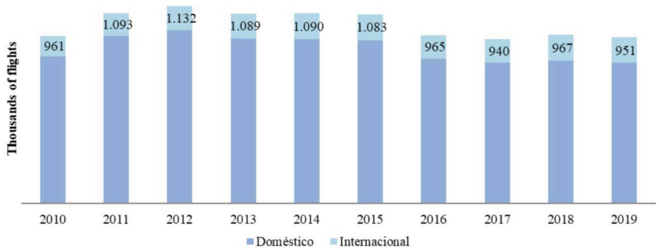

Fig. 1. Evolution of the number of flights in Brazil *Source*: ANAC (2019).

of 2015 and 2019, which we could view and upgrade and differences for centrality data.

Although the h-centrality has been introduced, application in transport system is limited. With h-centrality core list analysis we could verify main airports in the air network considering the characteristics from relevance and availability. When we consider the whole air network, the h-centrality core list provides the main hubs without any prior definition from decision maker.

The properties knowledge of layer centrality, which is based on classic degree centrality, is limited with few applications of case studies. Here, the analysis applied to airport review provides the ranking considering the relevance. Different from h-centrality, the layer centrality needs from decision maker a definition for top main airports a cut-off position previously.

The Section 2 presents the theoretical base of this study regarding centralities applied to air transport and the details for h-centrality and layer centrality. Section 3 shows the case application for the Brazilian air transport system and Section 4 with the conclusions for the paper.

2. Centrality measures

The definition of the central points of a network involves the identification of its most impacting points, which can be calculated based on centrality measures (Ercsey-Ravasz et al., 2012). Studies on centrality have a variety of application such as academic evaluation (Batista et al., 2018) or even a general industry assessment (Pereira et al., 2018).

In general, centrality evaluates the relative importance of a vertex in a network (Bergiante et al., 2011), and can be measured in several different ways, with different meanings and interpretations. Some centrality measures are related to the h-centrality and layer centrality: the centrality of degree that measures the amount of edges connected to the vertex; the centrality of layers that measures the influence of the neighbors, but by exclusion of the lower degree vertices, and the eigenvector centrality that measures the influence of the neighbours by linear combination.

2.1. Air network centralities

We verified that Jaillet et al. (1996) indicate the airport hubs influence the cargo sector as well where the greater frequency of flights easy the deliveries. Pereira et al. (2018) evaluate the network from a Brazilian airline company compare to classical centralities measures and providing the main airports through multicriteria method.

So Yaru and Lina (2012) verifies the choice of a hub and spoke network model by a company involves decisions looking for gains in scale for its operations as well as competition judgment where diverse players seek to maximize their profit.

Nevertheless, competition from large companies with low cost airlines weakens the margins at these big airports to large ones, as seen by Hansen (1990), in an analysis of the European network. This also influences the efficiency of companies according to Fageda (2014).

Then Martin et al. (2015) find that low-cost airlines tend to take on greater gains with point-to-point routes where they work practically in monopoly, and large companies tend to focus passengers on hubs to better utilize the air network.

Though, as seen by Martin et al. (2015), large companies are making alliances, such as Delta acquiring GOL shares in 2011, or creating low-cost subsidiaries such as Lufthansa on creation of Germanwings in 2012. Indeed, some aspects aid in the implementation of low-cost routes, as seen by Fageda et al. (2015) in the analysis of these factors in Taiwan, as the price government, the operational supporting efficiency and the airport authority with the policies. As indicated by Zhang et al. (2014) the high prices in the hubs pressure the fee of airline tickets and end up impacting the profitability of large companies (Lu and Mao, 2015).

As h-centrality and layer centrality are based in classical degree centrality, we shall recall the definition of this method.

2.2. Degree centrality

A network graph is identified by $G = (V,E)$, where V is the set of n vertices v_i and E is the set of m edges (v_i,v_j), each edge being formed by a pair of vertices of V, that is, $v_i, v_j \in V$ (Bondy and Murty, 2008). The matrix $A = A(G) = [a_{ij}]$; for which $a_{ij} = 1$, if $[v_i,v_j] \in E$, and $a_{ij} = 0$, if $[v_i, v_j] \notin E$, is called matrix of adjacency of G, being asymmetric for directed graphs.

Among other classical measures, the degree centrality (Freeman, 1978/79) is defined by the amount of edges connected to vertex v_i. Using the adjacency matrix A of the graph gives the degree centrality $C_D$of a vertex v_i by summing the values of its row or column, for non-oriented graph, as following (1)

$$C_D(v_i) = d(v_i) = \sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji} \text{ where } v_i \in V \text{ and } A = [a_{ji}] \quad (1)$$

For oriented graphs, each vertex has two centralities, one for output and one for input. The definition of output and input will determine the degree calculation in the adjacency matrix whether it will be by row or column only. Here we consider only non-oriented graph, as a symmetry matrix.

2.3. H-centrality

The centrality based on the h-index (Pereira and Soares De Mello, 2020) provides the central vertices by adjusting the bibliometric concepts of the h-index (Hirsch, 2005). This method is similar to degree centrality, which measures the number of adjacent vertices for each vertex analyzed, so-called neighbours.

From a graph $G = (V,E)$, where V is the set of n vertices v_i and v_j, while E is the set of m edges (v_i,v_j), which each edge is formed by a pair of connected vertices of V, in this case $v_i, v_j \in V$. We have h- centrality for v_i, defined by $C_H(v_i)$, is obtained in the ordering of the j vertices v_j decreasing by the sum number of connections (edges), so $\sum v_i v_j$ (or $\sum m$).

In the original h-index proposed by Hirsch (2005); v_i is the researcher, v_j is article, $\sum v_i v_j$ is the quantity of citations of article v_j and j is the order given decreasing by the number of citations. When the number of citations is below or equal than the order of paper listed, the h number (here called j) of a researcher v_i is determined. The h-centrality applied to any network is the number j, when $j \leq \sum v_i v_j$. In Fig. 2 is presented illustratively contrast of the h-index with h- centrality.

The j neighbors vertices of v_i which have $\sum v_i v_j$ at least the number h form the core list of vertices v_i (Burrell, 2007). The h-centrality differs from the other methods in literature since it has the prioritization by the quantity h of the adjacent vertices. This method presents the impact of the vertex analyzed, distinct from measure of degree or the measure of closeness which consider only the adjacent connections without to carry out the ordering.

We verified some studies which analyze the structure of the network of air routes through centrality measures, as Wittmer and Beritelli (2011) in an evaluation of Australia. They also verify and determine the

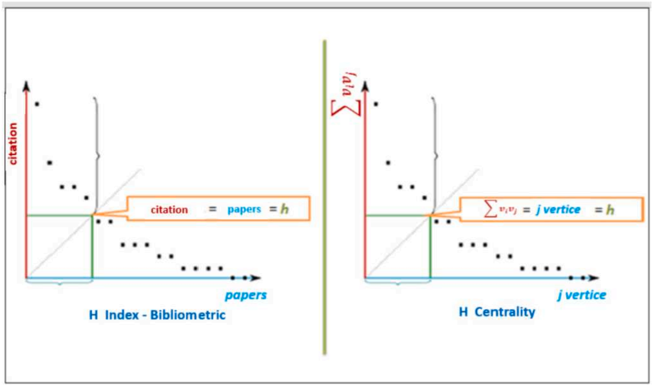

Fig. 2. H-index versus H-centrality comparative *Source:* Authors.

important hubs in the country, as well as the influence on the network of the airlines and also analyze the routes detailing competitions among companies.

In another approach, Wang et al. (2011) verify China's air network considering the measures of centrality for central cities directly linked to cities with greater economic activity. Therefore, the analysis of the companies' strategies of action depends on a greater management of the network of action.

2.4. Layer centrality

As Brandao et al. (2020) proposed a centrality measure based on concepts on Data Envelopment Analysis method of layer (Barr et al., 2000) which consists in evaluation of units considering its influence into the production frontier. In graphs view, the analysis reflects the influence of a vertex among the adjacent neighbours.

The first step of layer centrality is to identify from an adjacency matrix the element with the smallest sum of the coordinates on the line, and order it in the last place, thus considering it as the vertex of lesser centrality. The line and column of that element are then excluded in the matrix. This eliminates the vertex of the matrix, so it could not be ordered again, but it also eliminates the connections of the other vertices with that element.

All this process must be repeated, ordering the vertices in ascending order of centrality and excluding the respective rows and columns, until the last vertex of the matrix. If more than one element has the same summed coordinates in its lines, both must be ordered in the same position and have their rows and columns excluded from the matrix simultaneously. That is, these vertices are in the same layer. Fig. 3 shows an example of a graph ordering by layers excluding the vertex following the methodology, in this case we have 4 layers to be consider.

In terms of graphs, this methodology consists to identify the lowest degree vertex (s) and order it last. Next, a subgraph is created, in which all vertices except the one (or more) with the lowest degree are present. In the following iteration, the new degrees are calculated for the subgraph formed, again identifying the minor degree vertex (s), and removing it to form a new induced subgraph. This process is thus repeated until there are no more vertices to be removed.

The layer centrality shows a ranking of the vertexes by each relevance according the layer step considered, nevertheless the methodology does not provide any number of the measure for each vertex only the layer it came from.

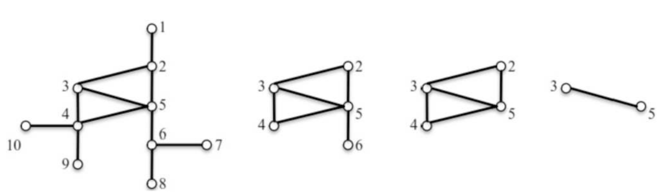

Fig. 3. Layer centrality excluding vertex process *Source:* Brandao et al. (2020).

3. Study of Brazilian air network

The data used in this study are based on the HOTRAN table, where the national civil aviation regulator ANAC (National Civil Aviation Agency) defines all regular commercial flights (domestic and international) for transporting of passengers including cargo. The table data was extracted of August 2015 and November 2019, where the direct routes for all the airports were listed.

The years were chosen to compare different situations of the Brazilian air transport industry. The year 2015 is a period between big event occurred in the country, as 2014 FIFA World Cup and 2016 Rio de Janeiro Olympic Games. However, 2019 is a year when a big airline stopped the operations due to bankruptcy.

In this paper a flight will be defined only as direct connection two airports. They verify a model for calculation of aerial accessibility of airports from the direct connections offered. Illustrating this concept of flight, consider the flight JJ3307 operated by Latam Airline with following itinerary: GIG – Galeão Airport, Rio de Janeiro/RJ × FOR – Fortaleza Airport/CE × Natal – RN × GRU Airport – Airport of Guarulhos/SP. In this case, 1 flight will be counted for each direct flight origin, i.e.: 1 flight to the GIG, referring to the GIG × FOR flight, 1 flight to the FOR, referring to the FOR × NAT and 1 flight to the NAT, section NAT × GRU.

The code used in this study is following the IATA (International Air Transport Association), which are better known for being the same used for ticket reservation. For example, for Santos Dumont Airport, which airport is in Rio de Janeiro-RJ, the code is SDU.

Some steps are followed before the determination of the Brazilian central network, according to the h-centrality measure. We start with data processing, where arbitrarily defined commercial flights of passengers with departures on Mondays, excluding from the HOTRAN table the freight flights and the postal network. Mondays present the largest number of destinations served and therefore the we can analyze the wide-ranging case of the network.

A matrix of adjacency with the core h-index of each airport is formed from the connections between the airports. However, the central network is defined by the square matrix, where you need to exclude the secondary airports, which are those that are not present in the airports core list.

We define a starting point and preferably starts at one of the largest airports in terms of the number of flights on the network. This method shall probably cover the final central network. Table 1 presents the core list ordered by the h-centrality measure in 2015 of the 6 main airports that form the central network of the Brazilian air network.

The importance of this central network is given by the representativeness of more than 50% of the approved flights within the Brazilian network considering these six main Brazilian (Pereira and Soares De Mello, 2019a,b).

Table 2 presents the core list ordered by the h-centrality measure in

Table 1
Brazilian airports H Centrality in 2015 Source: Authors.

H Centrality	Code	Airport	Region	Total Number of Flights
11	GRU	Guarulhos – SP Airport	Southeast	381
9	CGH	Congonhas Airport – São Paulo – SP	Southeast	238
8	BSB	Brasília – DF Airport	Central	288
8	GIG	Galeão Airport - Rio de Janeiro – RJ	Southeast	197
7	CNF	Confins – MG Airport	Southeast	278
7	VCP	Viracopos Airport – Campinas – SP	Southeast	331

Table 2
Brazilian airports H Centrality in 2019 Source: Authors.

H-centrality	Code	Airport	Region	Total Number of Flights
26	GRU	São Paulo [Aeroporto Internacional Guarulhos], SP, BR	Southeast	286
20	BSB	Brasília [Presidente Juscelino Kubitschek Intl], DF, BR	Central	179
20	VCP	Campinas (São Paulo) [Viracopos (Campinas Intl)], SP, BR	Southeast	113
19	CGH	São Paulo [Congonhas Intl], SP, BR	Southeast	269
16	CNF	Belo Horizonte [Tancredo Neves Intl (Confins Intl)], MG, BR	Southeast	115
15	REC	Recife [Guararapes Intl (Gilberto Freyre Intl)], PE, BR	Northeast	81
14	GIG	Rio de Janeiro [Galeão - Antônio Carlos (Tom) Jobim Intl], RJ, BR	Southeast	87
12	SSA	Salvador [Deputado Luís Eduardo Magalhães (Dois de Julho)], BA, BR	Northeast	79
12	BEL	Belém [Belém Intl - Val de Cães], PA, BR	North	40
11	SDU	Rio de Janeiro [Aeroporto Santos Dumont], RJ, BR	Southeast	146
11	CWB	Curitiba [Afonso Pena Intl], PR, BR	South	86
11	FOR	Fortaleza [Pinto Martins Intl], CE, BR	Northeast	63

2019 of the 12 main airports that form the central network of the Brazilian air network, an increase of main airport compared to Table 1, which represents almost 70% of the approved flights.

For the layer centrality, an adjacency matrix of airports is formed with all flights from data set, then the airports with the smallest connection number are excluded their line and column in the matrix.

In this case, these airports could not be ordered again, and also eliminate another vertices connection forming a new adjacency matrix. Besides measuring the influence of each vertex on neighbours, as other centrality measurements, the h-centrality also verifies the dispersion of such influence (Pereira and Soares De Mello, 2020).

Table 3 show the layer centrality Brazilian airports ranking in 2015. However, we shall define a cut-off layer to show the top airports. Herein, we show some airport from the list up to 29th layer.

Table 3
Brazilian airports Layer Centrality Network in 2015 Source: Authors.

Layer Centrality	Code	Airport	Region	Total Number of Flights
1	SDU	Santos Dumont Airport – Rio de Janeiro-RJ	Southeast	142
	VCP	Viracopos Airport – Campinas – SP	Southeast	331
2	CNF	Confins – MG Airport	Southeast	278
3	BSB	Brasília – DF Airport	Central	288
4	GRU	Guarulhos – SP Airport	Southeast	381
5	CGH	Congonhas Airport – São Paulo – SP	Southeast	238
6	POA	Porto Alegre – RS Airport	South	126
…	…	…		
16	NVT	Navegantes – SC Airport	South	37
	RAO	Riberão Preto – SP Airport	Southeast	44
17	CGB	Cuiabá – MT Airport	Central	67
18	NAT	Natal – RN Airport	Northeast	45
…	…	…		
28	LDB	Londrina – PR Airport	South	27
29	CGR	Campo Grande – MS Airport	Central	29
	MCZ	Maceió – AL Airport	Northeast	30

The Table 3 shows tied airports for some layers, and this is a limitation from layer centrality methodology where we could not define the difference among them. And also, as discussed before the layer centrality does not provide a measure number for the centrality.

Table 4 show the layer centrality Brazilian airports ranking in 2019. Herein, we show some airport from the list up to 29th layer, with some differences from 2015, where we could evaluate importance increase for airports in North and Northeast Brazilian regions.

As already verified by Ercsey-Ravasz et al. (2012) the central points of a network are verified by the most impacting points, and both the h-centrality and layer centrality analysis provide this identification, however the h-centrality provides the core list without any prior definition.

We highlight for the Southeast region as the largest number of airports in the network according to h-centrality core list, however we could check the results from 2015 to 2019 the increasing of others region importance. This result shows the difference from Pereira and Soares De Mello (2019a,b), where we verify the movement from some airlines companies using main Northeast big airports as hub to enable connection to many national or international destination.

With the h- centrality measure, this study presented the core list from whole Brazilian network. The layer centrality showed the top important airports. These analysis in common demonstrate the peculiar characteristics of the Brazilian aviation market, such as the distribution and concentration of operations. And the comparative study for both demonstrate the increase of importance for others region in Brazilian air network.

4. Conclusion

The original h-index reflects a history of the articles published by each author, but in the case of airports the market dynamics changes the behaviour of the network. As mentioned by Pereira et al. (2017), h-centrality measure presents the situation at the moment when the data were analyzed, which we could verify the same characteristic to layer centrality.

Table 4
Brazilian airports Layer Centrality Network in 2019 Source: Authors.

Layer Centrality	Code	Airport	Region	Total Number of Flights
1	SDU	Santos Dumont Airport-Rio de Janeiro-RJ	Southeast	146
	CGH	Congonhas Airport – São Paulo – SP		269
2	BSB	Brasília – DF Airport	Central	179
3	CNF	Confins – MG Airport	Southeast	115
4	GRU	Guarulhos – SP Airport	Southeast	286
5	POA	Porto Alegre – RS Airport	South	85
6	VCP	Viracopos Airport – Campinas – SP	Southeast	113
7	SSA	Salvador [Deputado Luís Eduardo Magalhães (Dois de Julho)], BA	Northeast	79
8	REC	Recife [Guararapes Intl (Gilberto Freyre Intl)], PE,	Northeast	81
…	..	…		
11	FOR	Fortaleza [Pinto Martins Intl], CE	Northeast	86
…	…	…		
20	MCZ	Maceió - AL Airport	Northeast	35
21	MAO	Manaus [Eduardo Gomes Intl], AM	Northeast	36
…	…	…		
28	LDB	Londrina – PR Airport	South	26
29	JPA	Joao Pessoa [Presidente Castro Pinto], PB, BR	Northeast	38

The period analyzed considers different challenges for the Brazilian air transport system, since 2015 is a period between big event occurred in the country, as 2014 FIFA World Cup and 2016 Rio de Janeiro Olympic Game, and 2019 is a year when a big airline stopped the operations due to bankruptcy.

The results in 2015, Pereira and Soares De Mello (2019a,b) shows a more concentrate network in Southeast region, different from we could verify here of data from 2019 where other regions present importance as well for the air network connectivity and influence.

As the air transport system smooths people mobility worldwide, the air transport is also a speed motor for diseases spread to different location. In this scenario, the centrality studies also improve the controls identifying the main hubs with influence in the network to facilitate the connectivity. This study was performed before the COVID-19 outbreak. However, the results could deeply vary by the volatility of airlines operations and demand worldwide (Pereira and Soares de Mello, 2021), so any centrality assessment are impacted directly due to passenger confidence or government restrictions.

As mentioned, the airline companies are using Northeast airport as hub to connect the region to many national or international cities, such as Azul Airlines in Recife/PE Airport or Gol Airline in Fortaleza. We also check some international companies with using Northeast airport as hub in codeshare with national airline, as the Portuguese TAP Airlines working together with Azul or Gol.

Additionally, further studies could be carried out to verify the interconnectivity of the global network, including Brazilian airports. Finally, another proposal for a future study could be to increase the data to consider the size of each airport as well as the types of aircraft that operate, to avoid discrepancies among the network.

CRediT authorship contribution statement

Deivison Da Silveira Pereira: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Visualization, Investigation. **Joao Carlos Correia Baptista Soares De Mello:** Supervision, Software, Validation, Writing – review & editing.

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