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Impacts of the halt of ITA flight operations on the Brazilian Multiplex Air Transportation Network

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Abstract. The bankruptcy of Avianca Brasil, the COVI-19 outbreak and the sudden halt of operations of Itapemirim Airlines in 2021 changed the topology of the Brazilian Air Transportation Network in past years. The effect was the reduction in the number of network layers and the network concentration. The aim of this paper was to characterize structural properties and evaluate changes in the Brazilian air network after the halt of operations of Itapemirim airline using a multilayer complex network. The multilayer approach considering the weight of interactions makes the network description more detailed than the usual monolayer analysis. We used data related to passenger traffic from November 2021 and January 2022 and each network layer represents an airline. The proprieties and centrality measures were used for Brazilian network characterization, which concentrated into four layers. Gol and Passaredo increased their market share and operating airports while Gol became the biggest market share. The number of routes increased for all airlines, especially Gol which increased by 24%. Gol became the densest layer with the minimum mean path length probably because ITA's layer had the highest correlation with Gol and edges overlapping. Results suggest Gol may have had the best strategy to incorporate the ITA's pent-up demand.

Keywords: Multiplex Networks, Air transportation, Network topology.

1 Introduction

The air transportation sector influences economic, political, and social aspects worldwide, by offering safe and fact intercontinental mobility. But, indirectly is responsible for the propagation of diseases, such as COVID-19. The aviation sector has social and economic development role in connecting remote destinations and regional aviation can be the means of accessibility in distant cities.

The COVID-19 outbreak disrupted the Air Transportation system on a large scale and reduced connections worldwide, with a different impact in each country. In Brazil, regional aviation has been facing major challenges outside large urban centres, especially because of the network concentration after the COVID-19 pandemic and the economic recession. Also, there is an effect of layers concentration as airlines have merged with others or faced a judicial liquidation process as in the case of Avianca Brasil (ONE) and now with the halt of flight operations of ITA.

Itapemirim Transportes Aéreos (ITA) halt operations on December 17, less than 6 months after the start of operations, when it collapsed due to debts with suppliers and employees. After they suspended operations, the company closed the agreement to sell the airline to Baufaker Consulting in April. The company would take over the R$ 180 million debts with airports, aircraft leasing companies, travel agencies, employees, passengers, and the Itapemirim Group [1]. With the acquisition and maintenance of the leasing of five aircrafts, type A320neo, the new controller intended to inaugurate a new transport model and said they would resume negotiations with the regulatory agency and with creditors for debt payments. However, in May, the company gave up on the purchase.

ITA is currently no longer able to operate, as ANAC has suspended its operator certificate.

On 5 May 2022, ANAC cancelled the Air Operator Certificate, as determined by publication in the Official Diary No. 7,940, because the company did not meet the operational requirements to keep the COA active. If ITA plains to return activities, they must restart the entire process.

When ITA was launched, the promise was to operate 50 aircraft in the company's second year. But the company suddenly halted operations and left R$ 80 million in tickets sold for future data, a repressed demand, which had an impact on Brazil's air transport network.

In 2011 the Brazilian government started the program of airport concession for the private sector, which led to another reorganization of the air network. Regional airports only started to be granted in 2019. Until 2021, 44 airports are in concession and 15 airports are going to be granted in 2022 in the 7th round.

Air transportation is a complex infrastructure system that is better described using the multilayer complex network approach and the weight of each interaction. Each layer in the air network represents an airline operating in Brazil, where airports are represented as nodes. The multiplex networks are complex systems represented by different multiple layers, where each layer consists of a network with one type of interaction. In this multiplex system, all layers are coupled together, given that each node might integrate more than one layer. The evaluation of network structure is fundamental to predicting and understanding dynamic processes and quantifying the importance of an airport is an effective measure to understand the structure of the Brazilian air transportation network.

The multiplex approach of the air network can reflect the expansion or reduction of each airline layer, to assess the internalization of air transport in the national territory. This research aims to assess the impact of the halt of ITA operations on the Brazilian Air Transportation Multiplex Network, evaluating the influence on airports' centrality, using topological characteristics and structural properties of the network.

2 Literature Review

Real-world systems can be represented using complex network theory, with nodes and links between them. In this study, the topological levels are divided into layers. The multiplex networks are a special type of multilayer network. In multilayer systems, there can be interlayer links between nodes and their counterparts in different layers (multiplex networks) or interlayer links between different nodes in different layers (general multilayer). Some examples of multiplex networks are trade networks between countries, transportation networks, social, biological, and financial networks. Many real-world systems are better described as a multiplex network than a single-layer network and air transportation is an example of a complex infrastructure system. In air transportation networks (ATNs), the layers can indicate different topics of collaboration, such as airlines, hub airports or countries. The multilayer approach is more accurate because it can identify important features and behaviour not observable in a single-layer network, for example, a different node centrality ranking, as travel can occur through different layers.

The complex network topology impacts the system's behaviour, therefore is essential to the analysis and modelling of complex networks. Research studies on topological structures are divided into normal situations and disrupted scenarios. The change of international connectivity of an ATN during disruption and the impact of ATN topology has rarely been studied, as the scale of disruptions by COVID-19, for example, is much larger than what has been studied yet (Zhou et al [2]). Usually, research studies about the change of performance on networks under disruptions use topology metrics, measures of robustness, vulnerability, and resilience.

Guimera et al [3] analysed the global structure of the worldwide air transportation network, a scale-free small-world network. They found that the most connected cities are not necessarily the most central, and this effect arises from the multi community structure of the network.

Demertzis et al [4] use an exploratory time-series analysis of the evolution of the COVID-19 disease in Greece detecting connective communities, where each node was considered a different day. The study aimed to forecast the disease spread with low availability of data.

Sun et al [5] investigated the impact of COVID-19 on global air transportation network on three different scales: on a worldwide scale, on a scale of international country networks, where the countries are contracted as nodes, and for domestic networks in specific regions and countries. They focus on spatial-temporal evolutionary dynamics for an empirical analysis from January to May 2020 and found connections reduced by 50% worldwide and the average betweenness centrality increases through the pandemic, as some airports with a hub role have been shut down, increasing the importance of other airports.

Oliveira et al [6] evaluated the evolution of the Brazilian domestic air network between 2010 and 2018, in a multiplex perspective but non-directed. They proposed a Multiplex Efficiency Index to quantify fluctuations in network efficiency. They used monthly and annual networks and concluded that the efficiency index increased with the network concentration in 2018. Also, four of six privatized airports had a greater or equal value of the index than before privatization. Although, they concluded that privatizations do not necessarily imply these changes but the expansion of airports, which happened even for public ones.

Xue [7] proposed a variability analysis to determine the magnitude of change in the main feature values of the global aviation network during COVID-19. The analysis is based on Harmonic Closeness Centrality, Betweenness Centrality and Eigenvector Centrality.

Silva [8] investigates the impact of the structure of the air transportation network on air ticket prices in Brazil. They proposed an economic meaning to the topological patterns of the networks and these measures in the context of air transportation. They found that the clustering coefficient and authority score are associated with lower average airfare prices. The degree, which means the convenience of transport, and the closeness centrality are attributes that raise the average price. They analysed the network structure of the air transportation network, but separately for each airline, not considering the influence of the connections between airlines.

The number of airlines operating regular flights in Brazil evidences the fragility of the competitiveness in the domestic air market. The fleet standardization in large aircraft may be considered a limiting factor to encourage competition on routes with low-density in traffic (Ventura et al[9]).

3 Method

In this research, we use the tensorial formulation of multilayer networks, an approach that can surpass the limitations of individual networks structure for each layer or an aggregated network. The single-layer approaches can lead to misleading results and generalize the usual centrality measures of the network. To conduct this study, we use the theoretical assumptions of De Domenico et al [10, 11, 12].

A multiplex network with M layers, each one having the set of nodes N is represented by the adjacency matrices $\mathcal{A} = \{A^{[1]}, A^{[2]}, \dots, A^{[M]}\}$. With the adjacency matrices, the distance distribution of nodes can be calculated for each node i in layer $\bar{p}$ $(\mathcal{N}_i^{\bar{p}}(d))$. The distance distribution is the fraction of nodes that are at distance d, the shortest path, of node i in layer $\bar{p}$ (Oliveira et al [6]). Like single-actor measures, the multilayer distances are computed between pairs of actors. The path between actors continues on any layer where the corresponding actor is present and can traverse multiple layers.

For weighted networks, two matrices need to be described: the adjacency matrix and the matrix of weights. In this research, nodes might (or not) exist in all the layers, which can be measured by the multiplexity, and the interlayer links occur only between nodes and their counterparts.

As the objective was to compare the network with ITA operating and then after it stopped operating, we gathered public data from the National Civil Aviation Agency (ANAC) from November 2021 and January 2022 of domestic and international flights. Also, we filtered only major Brazilian airlines that carried at least 0.5% of the total passengers, except for unproductive flights and non-passengers flights. Data were pre-processed, then imported and processed on the MuxViz open-source software and R library (De Domenico et al [12]).

In this ATN, nodes represent the airports, and the links are direct flights between them. Both networks are directed (links have directions) and weighted (the weight is the sum of passengers carried on that route). The flights for each airline were divided into layers, whose characteristics were calculated as the number of nodes, connections, density, the number of connected components, diameter and mean path length. Also, versatility measures were obtained for each airport such as the node's strength, degree, PageRank, Eigenvector, Hub, Authority, Multiplexity, Katz and k-core. Centrality measures are important ways to identify the most relevant nodes in a network and the indices are used to produce a node ranking for each measure. We emphasize calculated measures are accurate for only this context of importance.

We compare the topological characteristics of the network in November 2021 and in January 2022 to evaluate the impact of the ITA operations in the Brazilian ATN. We also analyzed the versatility ranking position of the airports on concession, ITA's market share and the layers correlations. After that, we discuss the impact on every airline layer. Therefore, the analysis is based on operational and complex network indicators.

In complex networks, the distance between two nodes is the number of edges in the shortest path that connects them, the geodesic distance. The average path length (L_G) in a graph *G* with vertices *V*, in which $d\ (v_1, v_2)$, where $v_1,\ v_2\ \in V$, indicates the shortest path distance between vertices $v_1,\ v_2$ and can be assessed with the equation:

$$L_G = \frac{1}{n\ .(n-1)}\ .\sum_{i\neq j} d\ (v_1, v_2) \tag{1}$$

where *n* is the number of vertices in the network *G*. A network with a short path distance length has a quicker transfer of information with reduced cost. The average path length changes proportionally to *log n* and is 0 if one vertex cannot reach the other. Most networks have a short average path length, a small world characteristic.

The node degree is the number of edges connected to a vertex. In a directed graph a vertex has both an in-degree and out-degree, the number of in-coming and out-coming edges, and the total degree is their sum.

The network diameter is the length of the longest geodesic path between two vertices, which can be multiple, which means the shortest distance between the two most distant nodes and represent the linear size of a network. For weighted networks, MuxViz considers the edge weight to calculate the diameter.

Density is the number of connections a network has divided by the total possible connections it could have, therefore the ratio of edges (E) to all the possible edges in a network of (N) nodes. Given that the maximum number of connections in a complete network is $N\ (N-1)/2$, the network density is:

$$D = \frac{E}{N(N-1)}\ for\ oriented\ graphs;\ D = \frac{2\ E}{N(N-1)}\ for\ non\ oriented\ graphs \tag{2}$$

The network density can also be calculated by the number of edges divided by the number of nodes, the method used by MuxViz.

The measures of similarity between layers used in this paper are: mean global node overlapping, mean global edge overlapping and inter-layer assortativity. The mean global node overlapping is the fraction of node which are common to all layers, the same for the mean global edge overlapping, that measures the fraction of edges which are common to all layers. The Pearson correlation between the node degrees and their counterparts in the other layers is calculated for all pairs of layers to assess the inter-layer assortativity. The Spearman correlation is calculated for the same purpose and is recommended when the assumptions underlying a Pearson test are not satisfied, which is the level of measurement, absence of outliers and linearity.

4 Results and Discussion

To define the layers of operating airlines, we analyzed the market share of the Brazilian Air Transportation network. In Table 1 we have the total of paid passengers for each airline in November/2021 and January/2022, and we considered the main airlines the ones with at least 0.5% of the market share. After ITA stopped operating its flights, there was an increase in Gol’s market share and raised from the third to the biggest market share in Brazil. There was also an increase in the market share of Passaredo, while the other airlines had a reduction.

The Brazilian Air Transportation Multiplex network was composed of five layers: Azul (ICAO code: AZU), Gol (GLO), Latam (TAM), Passaredo (PTB) and ITA (IPM), in November/2021. While in January/2022 the Brazilian ATN had four airlines operating after ITA halted flight operations.

Table 1: Airlines' market share

	November/2021		January/2022	
Airlines	PAX (millions)	Market share	PAX (millions)	Market share
Azul	2,343	33,4%	2,246	29.0%
Gol	2,005	28.6%	2,764	35.7%
Itapemirim	103	1.5%	-	0.0%
Passaredo	42	0.6%	54	0.7%
TAM	2,508	35.7%	2,657	34.3%
Others	18	0.3%	21	0.3%

In November 2021, the Brazilian Air Transportation Multiplex network had 155 nodes and 1,129 links, a directed and weighted network composed of five layers. In comparison, the Brazilian ATN had 170 nodes and 1,146 edges in January 2022, with the four airlines remaining.

The total average degree of the network decreased from 54.66 (in-degree and out-degree) in 2021 to 37.56 in 2022, a variation of 31% indicating a loss of connections in the multiplex network. Table 2 shows the topology characteristics of the Brazilian Air Transportation Network in November/2021 and December/2022 for each layer.

Table 2: Brazilian Air Network Characteristics

	Layers	Nodes	Edges	Density	Density (%)	Diameter	Weakly/Strongly Connected Components	Mean Path Length
Nov/21	Azul (AZU)	95	471	5	10.5	16,813	60/61	2.4
	Gol (GLO)	58	275	4.7	16.6	25,796	97/98	2.2
	Latam (TAM)	63	272	4.3	13.9	27,396	92/93	2
	Passaredo (PTB)	22	45	2	19.5	7,482	134/135	2.6
	Itapemirim (ITA)	15	66	4.4	62.9	5,518	140/140	1.7
Jan/22	Azul (AZU)	102	472	4.6	9.2	16,263	68/68	2.4
	Gol (GLO)	60	343	5.7	19.4	25,721	110/110	2.1
	Latam (TAM)	67	281	4.2	12.7	36,204	103/106	2.1
	Passaredo (PTB)	24	50	2.1	18.1	6,978	148/148	2.5

Analyzing the Brazilian Air Transportation Network there was a growth in the number of nodes from November to January, which means the airlines expanded their operations adding new airports to the network, especially Azul (+7%) and Passaredo (+9%). Passaredo started operating to Cabo Frio (SBCB), Presidente Prudente (SBDN) and Fortaleza (SBFZ). And Azul started operating in regional Brazilian cities and Maldonado – Uruguay (SULS). On the other hand, the number of routes maintained almost the same for all Brazilian airlines, with a slight increase, except for Gol, which increased by 24% the number of air routes.

In general, Passaredo had significant changes in its network topology, expanding its network size operating in more airports, even with a few flights. The impact of those changes is the reduction of the network density and mean path length. Given that, results suggest that the other layers increased after ITA suspended their operations, probably to attend to ITA’s pent-up demand.

In this research, we are comparing networks of different periods, and January is high season demand, which can also explain the airlines’ network growth. However, both months compared are in the same season of slots, W21 (Winter 21) which means they have the same operations characteristics. ANAC currently is responsible to coordinate slots of five airports in Brazil: Guarulhos, Congonhas, Pampulha, Recife and Santos Dumont. And eight facilitated airports, where the coordination of slots is done by the airport administrator itself. Therefore, there is no bias regarding different seasons of slots. ANAC issues two seasonal flight plans a year – the summer timetable (from late March to late October) and the winter (from late October to late March of the next year). Even though, the causality effects may be studied in future studies.

Although the calculated diameter in MuxViz considers the connection weight, there was an increase in the diameter of Latam and Passaredo. In Table 2, we also compare the MuxViz density and the calculated density (%) using equation (2). All airlines reduced their network density, except for Gol, which increased its density. ITA had the highest calculated density, different from all the other layers. AZU was the densest layer in November followed by GLO, but in January Gol became the densest layer. This analysis shows a different result, as GLO and TAM were usually the densest layers in the network in 2019 and 2020, according to [13].

Guarulhos is the most central and important airport in both networks, regarding strength, degree and all the versatility measures. Viracopos has the second highest PageRank, Brasília is the second biggest hub and Congonhas the second biggest authority (receive more flights).

IPM used to operate in 15 airports (Table 3), with the biggest market share in Guarulhos, Galeão and Brasília. Even after IPM stopped operations, Guarulhos continued to be the most central and important airport. Brasília continued with the same versatility ranking, the second regarding degree, eigenvector, hub and third in PageRank.

Table 3: IPM Market Share

Airports	Passengers	Market Share	Airports	Passengers	Market Share
SBBR	13,166	12.7%	SBNT	4,163	4.0%
SBCF	4,123	4.0%	SBPA	6,053	5.9%
SBCT	1,614	1.6%	SBPS	3,956	3.8%
SBFL	2,806	2.7%	SBRF	5,926	5.7%
SBFZ	4,773	4.6%	SBSP	1,587	1.5%
SBGL	19,982	19.4%	SBSV	6,495	6.3%
SBGR	22,909	22.2%	SUMU	1,614	1.6%
SBMO	4,096	4.0%			

The most significant impact of the halt of ITA's operations was in the versatility of Galeão. Although Galeão changed from 8th to 7th in the degree ranking, the airport fell in the ranking of PageRank centrality (10th to 15th), Eigenvector (16th to 18th) and Hub (16th to 17th). This effect is probably because Itapemirim represented 10.4% of traffic in SBGL in November, while represented only 2.0% in Guarulhos and 2.3% in Brasília.

During the calendar of slots allocation of Winter 21 (W21), IPM requested almost the same number of slots as Azul in the initial submission in Guarulhos. IPM's operation had been growing month by month, but the company's strategy did not allow the operation to be maintained and the airline was not able to operate all those slots. Therefore, they returned most of the slots or canceled flights. After IPM halted operations in December, they did not return all slots immediately to ANAC, impacting the slots coordination of the airports, especially Guarulhos which could not use the IPM slots before their solicitation to ANAC. As the slots cannot be negotiated and depend on a specific order of allocation priority used by ANAC (according to the ANAC resolution 682), Guarulhos had to operate with ITA allocated slots until 2022. However, IPM as a new airline was not a priority in the allocation of peak hours and did not affect these hours.

Table 4: Correlations of IPM layer

Itapemirim Correlations	**Azul**	**Gol**	**LATAM**	**Passaredo**
Node Overlapping	0.09	0.09	0.09	0.05
Edge Overlapping	0.02	0.08	0.06	0.04
Pearson Correlation	0.33	0.85	0.74	0.46
Spearman Correlation	0.41	0.52	0.50	0.33

In Table 4 we have the inter-layer assortativity using the Pearson degree and Spearman degree. When we analyze the nodes' overlapping clusters, ITA is considered a separate cluster. But when the clusters are made using edge's overlapping, ITA stays in the same group as Passaredo. However, the highest correlation is with Gol. In the case of the short path distance similarity, ITA stays in the same cluster as Passaredo, and Azul is the most isolated cluster.

ITA had the same correlation on node overlapping as Azul, Gol and LATAM (Table 4). While the highest correlation on edge overlapping was with Gol. Also, ITA had the highest Pearson and Spearman correlation with the layer Gol. These results can explain the rise in Gol's market share during this period, absorbing the demand of the overlapping routes they operate and probably expanding its connections to incorporate the pent-up demand and ITA's layer routes. Therefore, it suggests Gol may have had the best strategy to incorporate the ITA demand.

5 Conclusions

This paper evaluates the current topological proprieties with an operational and empirical analysis of the Brazilian Air Transportation Multiplex Network, considering the impact of ITA airline halt of flight operations in December 2021, covering domestic and international passenger traffic. We used a multiplex approach with weighted links to analyze the network topology, for a better understanding of features that emerge in a multilayer system.

The impact of the halt of ITA operations in the Brazilian Multiplex Air Network increased Gol's network connections (+25%), while the other layers maintained their connections. Passaredo had also significant changes in network topology because even with an increase in the network size, the number of connections resulted in a sparser network with a greater mean path length and diameter.

Therefore, results suggest the companies absorbed ITA's demand by attending a higher number of nodes and increasing connections. Especially Gol, which had the highest edge overlapping with ITA, and the highest Pearson and Spearman correlation. Also, Gol is the only airline that increased its density during this period, probably to incorporate ITA demand. Results suggest Gol may have had the best strategy to incorporate the ITA's pent-up demand, increasing connections and having the highest market share in January 2022.

The limitation of this study is the air network characteristics of the different months, as January is historically a month with higher demand, even though we are comparing months within the same slots season (W21), therefore with similar characteristics of flights. Also, the COVID-19 situation and the vaccines, allowed the traffic demand to increase in January. Therefore, further studies are necessary to separate the influences of ITA's operations and macroeconomic effects.

The obtained results can provide an understanding of the network robustness and changes after layer concentrations, giving an insight into the development of required infrastructure and possible government incentives to enhance regional connections and the airlines' competitiveness in the next years.

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