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A model to identify airport hubs and their importance to tourism in Brazil

Tiago F.G. Costa [a], Gui Lohmann [b,*], Alessandro V.M. Oliveira [a]

[a] Latin American Center for Transportation Economics, Aeronautics Institute of Technology, Praça Marechal Eduardo Gomes, 50, Vila das Acácias. CEP 12228-900, São José dos Campos, SP, Brazil

[b] School of Travel Industry Management, University of Hawai'i at Mânoa, 2560 Campus Road, George Hall 346, Honolulu, HI 96822, USA

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A B S T R A C T

Air transportation in Brazil has been recently liberalized and one of the consequences of this process is the concentration of flights in a few hubs. During the years 2006–2007 two fatal accidents created unprecedented chaos in both land and air sides of the system with harmful consequences to tourism in Brazil. The consequences were more airport congestion and many episodes of flight delays and cancellations that lasted for several months. We argue that, among other factors, this state of blackout was a result of the increase in the degree of concentration in few airports, particularly Congonhas (in São Paulo) and Brasília. Using data obtained from a survey with Brazilian experts, a comparison was made with two existing methods (the one used by the US Federal Aviation Administration and the usual Herfindahl–Hirschman method) in order to calculate the number of hubs in Brazil. Due to the huge discrepancy obtained between data from the survey and the other two methods considered, a new mathematical method based on the Herfindahl–Hirschman Index was proposed to identify the number of hubs in a given network. Drawing from the examples of what happened to tourist destinations during and after the air transport crisis in Brazil, the article concludes discussing the need for a more accurate tool to identify and to monitor the concentration of flights at the Brazilian air transportation network and its importance to tourism.

1. Introduction

Hub-and-spoke (HS) networks are found in several areas of modern society, including transportation, telecommunications and logistics (Horner & O'Kelly, 2001). In air transportation, HS networks appeared for the first time in 1955, when Delta Air Lines used Atlanta as its hub, in an effort to compete with Eastern Air Lines in the south-eastern part of the United States (Babcock, 2002). After the US deregulation in 1978 and the European deregulation process that took place between 1987 and 1997, HS networks were adopted by most of the full-service airlines that operated in deregulated markets (Alderighi, Cento, Nijkamp, & Rietveld, 2005; Martín & Voltes-Dorta, 2009).

The major advantage of the HS network is that it allows airlines to reduce the costs of travel and increase their connectivity (Pels, 2001). The airline's cost of travel is reduced, as grouping passengers with the same travel origin but different destinations are gathered in feeder flights, which are then distributed in connecting flights from the hub to their final destinations. In addition, the connectivity is increased within the hub by concentrating landings and takeoffs at the hub, commonly called hub waves (Alderighi et al., 2005). Although it may enhance carriers' production efficiency, on the other hand a hub airport typically provides airlines with some monopoly power to control scarce airport facilities (Nero, 1999). In addition, they swell the operations in these airports used as hubs potentially increasing airside and landside delays, entail a barrier to new airline entry, increase detour level in the network and the airspace congestion, overworking controllers and threatening safety (Button, 2002; Hoffman & Voss, 2000; Rodrigue, Comtois, & Slack, 2006; Oliveira & Salgado, 2006).

In spite of the huge importance of hubs, there is little consensus among scholars regarding a precise definition for a hub. As an example, Burghouwt (2007) provides a list of fifteen definitions from different scholars. Nevertheless, it is possible to identify some congruence among these definitions. One of them is the word 'concentration'. The concentration of traffic in both space and time means that airlines consolidate their operations so that traffic from a diverse range of origins can be distributed to a diverse range of final destinations. In this sense, O'Kelly (1998, p. 171) summarizes that "hubs [...] are special nodes that are part of a network, located in such a way as to facilitate connectivity between interacting

* Corresponding author. Tel.: +1 808 956 0485; fax: +1 808 956 5378.
E-mail addresses: tiagofgc@ig.com.br (T.F.G. Costa), glohmann@hawaii.edu (G. Lohmann), a.v.m.oliveira@gmail.com (A.V.M. Oliveira).

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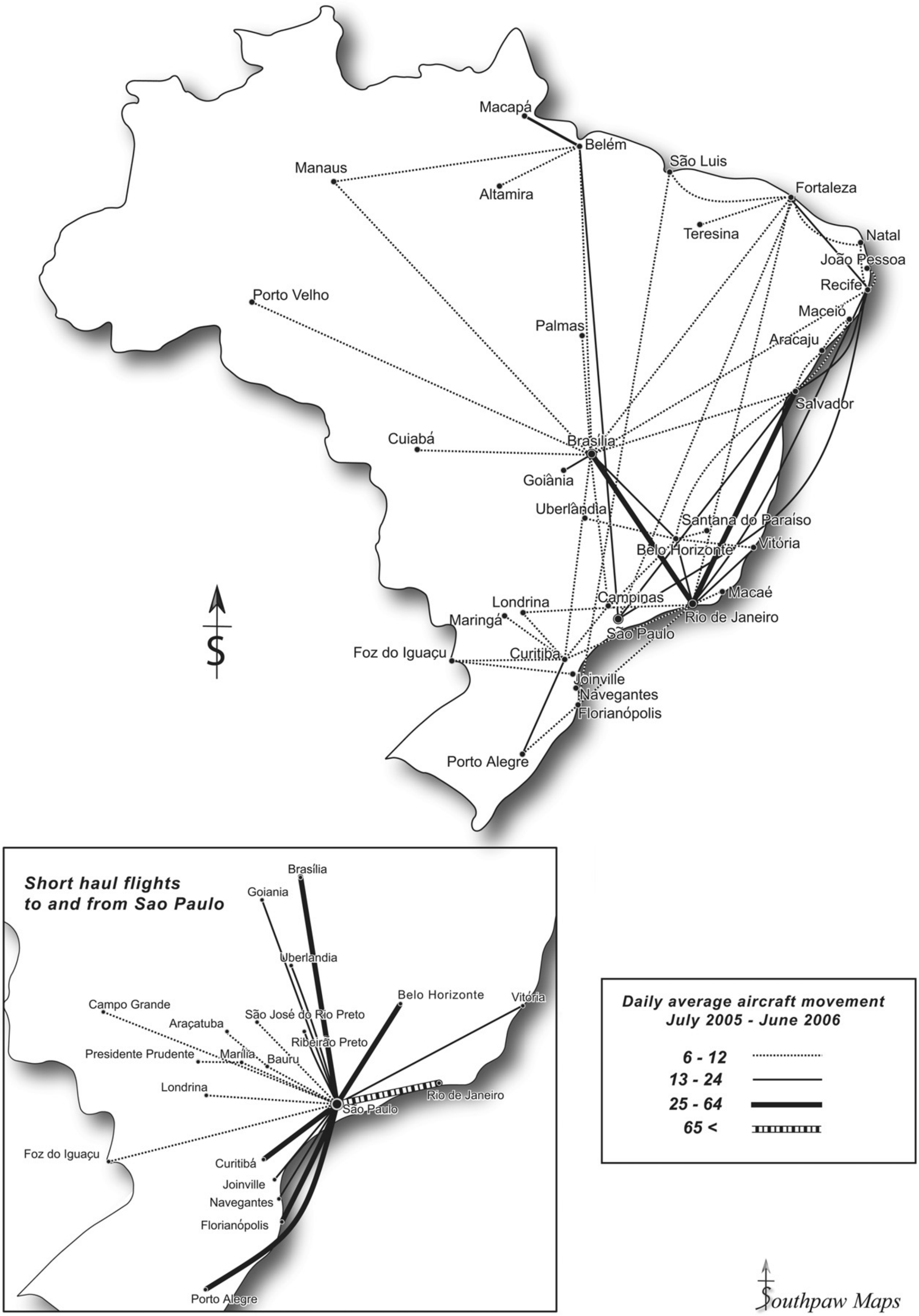

Fig. 1. Aircraft movements to top airports in Brazil during the period July 2005–June 2006 – only routes with six or more average daily flights are presented.

places". Apart from the concentration-distribution characteristic, centrality is also another key term usually associated with hubs (Shaw, 1993). Lohmann, Albers, Koch, and Pavlovich (2009), for example, describe the advantages that Singapore and Dubai achieved in terms of their location and central position by developing a hub network to improve not only air traffic but also tourists to their destinations.

Another common aspect identified among some of the definitions presented by Burghouwt, it is the fact that an HS network should have a limited number of hubs. For example, Button, Haynes, and Stough (1998, p. 20) affirm that "in hub-and-spoke operations, […] carriers generally use one or more large airports". Kanafani and Ghobrial (1985) state that the concentration of flights occurs at few airports, while Oum, Zhang, and Zhang (1995, p. 837) affirm that an airline's operation using hub-and-spoke networks will occur at one, or very few, hub cities.

Considering the lack of a single definition for a hub and the fact that HS networks should have few hubs, the question to be posed then is: how to identify or measure the number of hubs in a given network? A considerable number of studies have tried to operationalize the definition of a hub and, overall, their focus has been on the airline network, rather than the airport in itself. Calculations are heavily based on standard economic concentrations measures, such as Theil/Entropy measures, Coefficient of Variation, the Herfindahl indices and the Gini index (Alderighi et al., 2005; Burghouwt, Hakfoort, & Ritsema van Eck, 2003; Martín & Voltes-Dorta, 2009; Reynolds-Feighan, 2001).

As in many other parts of the world, air transport in Brazil went through a deregulation process, aiming to improve competition among airlines. Indeed, according to Oliveira and Salgado (2006) the deregulation process reduced fares and increased operational efficiency and competitiveness, but airports and air traffic control were not deregulated or privatized. They stayed under the government management. These factors combined to build a peculiar network design (see Fig. 1 for the concentration of traffic in the cities of São Paulo – inset map - and Brasília – large map) that ended up contributing for two of the worst air transport accidents in the country (with 354 fatalities), and repercussions to the whole domestic air transport system that lasted between 2006 and 2007. In the case of the first accident (in 2006), initially air traffic controllers in Brasília were blamed, but not willing to assume full responsibility for this fatality and also blaming the lack of investments in infrastructure (TCU, 2006), they decided to adopt a slowdown work procedure of following exactly what prescribed by the regulation, particularly in relation to the number of aircrafts they can handle at a time (Endres, 2007). As the air traffic control system in Brazil was underfunded, with fewer and not well-qualified controllers, several flights had to be systematically canceled or were delayed and many scary potential travelers changed their plans for domestic trips (G1, 2006). This includes not only changing the choice of destinations visited, but also the modes of transport used. Consequently, domestic tourism was heavily impacted. The second accident (in 2007) happened in Congonhas, the busiest airport in the country. The lack of confidence in the system, not only from the point of view of safety, but also in terms of punctuality and the stress travelers were under wondering about whether their flights would be available, made the authorities finally to take action. The first decision was to restrict connections and long haul flights from Congonhas Airport, with direct flights only to destinations located within a distance of 1000 km. This ultimately transformed its characteristic from a national hub into a regional airport (Knibb, 2007). Unfortunately, these measures did not last long.

Hence, the aims of this article are three-fold. Firstly, we discuss the recent air transport crisis that took place in Brazil. There are several factors to explain what the media has labeled as 'air transport blackout'. We argue that one of the key reasons for the two fatal accidents and the repercussions that followed is the concentration of flights at two major hubs, i.e. Brasília and Congonhas. The impact of this crisis on tourism in Brazil is then presented. Secondly, we compare data obtained from a survey with Brazilian experts with two existing methods to calculate the number of hubs in Brazil: (1) the method used by the US Federal Aviation Administration–FAA; and (2) the NEP method. Thirdly, due to the huge discrepancy obtained between data from the survey and the other two methods considered, a new mathematical method based on the Herfindahl–Hirschman Index is proposed to identify the number of hubs in a given network. We conclude stating that having a better method to identify and monitor the number of hubs can serve as a tool for policy makers, air transport organizations and other stakeholders involved with it, including tourism enterprises and agencies, to evaluate the degree of concentration of a given network. We assume that hubbing is a choice by airlines and is clearly driven by economic incentives. Our claim here is that by permitting a better identification of hubs our method allows authorities to better plan and induce the path of infrastructure investments. In the end, concentration driven by economies of hubbing will occur without causing unwanted congestion and externalities that more than compensate those economies. Undoubtedly, in a deregulated market, this identification by authorities does not modify hubbing decisions and certainly will not directly influence airline networks. However, with a clearer identification of airlines' strategies towards hubbing authorities are able to design specific policies regarding major airports. For example, Ramsey pricing combined with slot allocation may be designed in order to induce airlines to behave in such way that congestion is avoided and secondary airports are benefited.

2. The 2006–2007 air transport crisis in Brazil and its impacts on tourism

With the introduction of the Air Transport Liberalization Policy in the 1990s, the rigid structure existing in Brazil diminished the economic regulation that used to control the sector. New small airlines started to have access to air transport markets that became more competitive. In 2003, after a certain period of economic

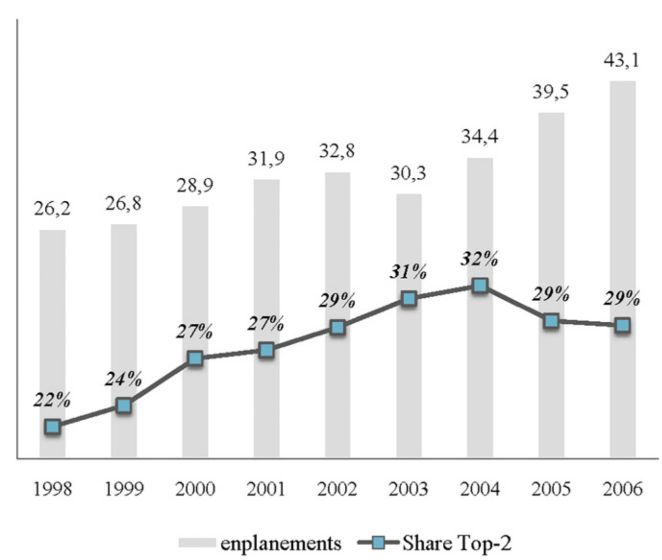

Fig. 2. Domestic enplanements (in million passenger boardings per year) and the share of top-two largest airports in Brazil.

freedom, regulation was imposed again due to what was considered as an "excess in capacity" and "predatory competition" in the market (Bettini & Oliveira, 2008). Nevertheless, there are clear signs that the Liberalization Policy brought many benefits, such as lower airfares, higher operational efficiency and competitiveness through market expansion. However, the same economic liberalism was not applied to the sector's lagging infrastructure, including airports and air traffic control.

One of the negative aspects of the liberalization process was the concentration of aircraft movement into key airports, particularly in two major airports located in the city of São Paulo (Congonhas and Guarulhos) and Brasília's airport. Fig. 1 illustrates all city-to-city routes in the country with pairs of routes with six or more average daily flights (three return trips) and provides a visual demonstration of the importance of the city of São Paulo, where Congonhas and Guarulhos airports are located, and Brasília, the capital city, as the key hubs and the bottlenecks of air transport system in Brazil. These two cities also became the epicenter of the worst air transport accidents in the country.

The first accident happened in September 2006, when a mid-air collision occurred between a Boeing 737 from Gol Airlines and an Embraer Legacy 600 executive jet. The executive jetliner was able to land safely, but all 154 passengers and crew onboard Gol's Flight 1907 were killed. At the time of the accident, both airplanes were being handled by the air traffic control in Brasília. After that, in October 2006, a breakdown in one of the country's radar systems (Cindacta 2 – Integrated Center for Air Defense and Traffic Control) located in Curitiba caused delays in at least 146 commercial flights. In the same month, the investigations about the air collision started and the air traffic controllers were feeling pressured. On November 2nd, of the same year, a group of air traffic controllers went on strike in the Brasília air traffic control center (Cindacta 1), which handles the Center-West and Southeast regions of Brazil, accounting for 75% of Brazilian air traffic. Flight delays were spread throughout the country, leaving a crowd of passengers in airport lounges of Brazilian major cities. As a result, in December 2006, 55% of all flights were delayed and for several months air transport system in Brazil was not considered reliable anymore (Folha de S. Paulo, 2006b). The first half of 2007 was flagged by several new strikes, massive delays and a widespread discussion in the Brazilian society, including the Congress, which installed two investigative commissions to deal with the airports problems. However, in July 2007, another fatality happened when an Airbus A320 from TAM Airlines slipped off the airstrip at Congonhas airport, in São Paulo, and crashed into a building causing 200 deaths.

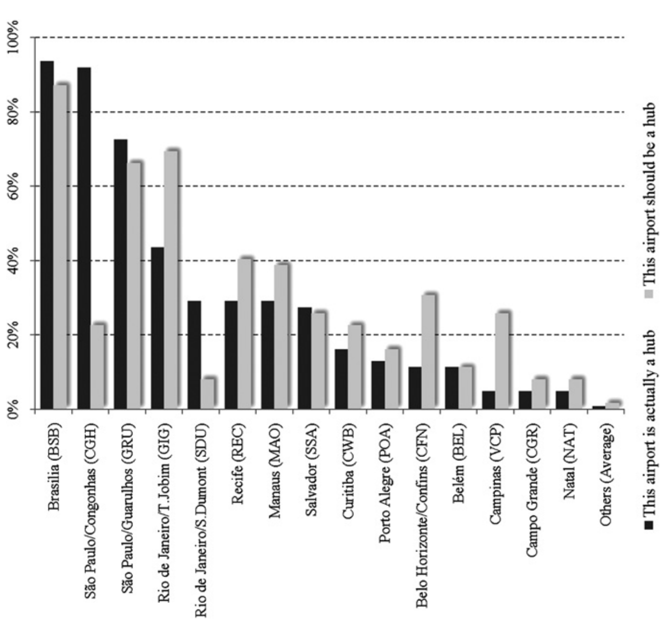

Fig. 3. Airports that are hubs and that should be hubs according to the responses obtained from a survey with air transport experts ($n = 79$).

These events highlighted the main problems in the Brazilian airport network and brought the discussion about the high growth of air transportation traffic and the negative impacts it imposed on the lacking infrastructure and its concentration on few airports. The various specialists interviewed by the media during the air transportation crisis suggested that while the system was clearly affected by operational issues including an overall lack of investments in the airside (runways, control towers and air traffic control), lack of transparency and managerial issues related to the military control of the air traffic control system and the concentration of traffic on very few hubs (Endres, 2007; Knibb, 2007). Air transport authorities also acknowledged these issues as the first decisions made after the second accident was to restrict long haul flights in Congonhas airport and the discussion to expand Guarulhos airport or to build a third airport around the city of São Paulo.

The repercussions of the first accident were felt in many areas, including tourism, one of the most affected sectors (Brancatelli, 2007). As a result, some potential tourists cancelled their trips, while actual travelers shifted their mode of transportation from air to road (cars and busses) or even decided to take a cruise vacation. At the end of 2006, the highway traffic intensified with some estimations of a 25% increase in comparison to the previous year, particularly in the states of São Paulo, Minas Gerais and Rio de Janeiro, which are the largest domestic-tourist generating states within the country (G1, 2006).

The impact of the crisis was particularly severe to the coastal resort destinations in the Northeast region of Brazil, such as Fortaleza, Natal, Recife and Salvador (see Fig. 1). They distance between two and three hours by plane from the key generating markets with visitors from these states opting to travel to nearby destinations. Package sales, for example, were down by 8% in December 2006, affecting particularly hotel cancelations in destinations located in the Northeastern and Northern parts of Brazil. Overall tourism demand in the Northeast region of the country were down 35%, with over 15,000 hospitality employees been dismissed. A huge increase in the demand for cruise tourism was also identified, presumably influenced by the fact that most of the ships depart from the ports of Santos (less than 60 km from the city of São Paulo) and Rio de Janeiro, two of the largest tourist generating cities in the country. Approximately 70,000 extra tourists took a cruise in Brazil in the 2006/2007 season, in comparison to the 2005/2006 summer months (Folha de S. Paulo, 2006a).

3. Assessing airport concentration in Brazil

The deregulation of the US domestic passenger aviation in 1978 was followed by a notable concentration of traffic around a small number of central airports or 'hubs'. This phenomenon has been observed in recently liberalized markets all over the world, with major airlines aiming at consolidating their networks to enhance efficiency and market power. In Brazil, the same trend was observed in recent years. Fig. 2 presents the evolution of domestic enplanements from 1998 to 2006. It is possible to note the fast growth of the industry, with a production of 16.9 (43.–26.2) million additional enplanements within the period. This represents a 64% increase in nine years. Additionally, the industry has also experienced a notable increase in airport concentration. In fact, the concentration ratio of the two major airports (hereafter to be

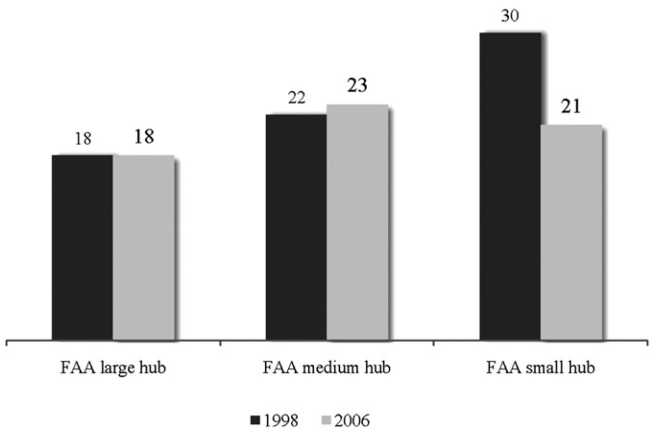

Fig. 4. Number of hubs in Brazil according to the FAA methodology.

mentioned as C-2 ratio), São Paulo/Congonhas and Brasília airports, has apparently increased from 22% in 1998 to 29% in 2006, with a peak of 32% in 2004.

Our aim here is to verify whether the increase in the C-2 ratio was really an indication of a higher concentration of networks within the domestic air transportation system in Brazil. To accomplish that, we make use of a proposed methodology for assessing network concentration in air transportation. Indeed, many authors such as Alderighi et al. (2005), Huber (2008), Martín and Voltes-Dorta (2009) and Reynolds-Feighan (2001) aimed at assessing major impacts caused by liberalization and competition on the air transportation networks by directly measuring concentration. The concentration measures found in the literature are usually related to the Gini or Herfindahl–Hirschman (HHI) concentration indexes. Burghouwt et al. (2003) propose a correction for the standard Gini index (the "NC-Gini") that makes it possible to compare the spatial structure of airline networks independent from network size. Here we make use of the HHI-related procedure with a simple and direct adjustment for the network structure of carriers in order to assess the concentration path in the Brazilian airline industry since liberalization. We aim not only to measure the concentration but also to identify what are the hubs in the country. We believe that other measures such as the proposed by Martín and Voltes-Dorta (2009) may be used to assess concentration in order to permit comparisons with our results. However, we let those analyses for future work.[1]

3.1. A survey on the airline hubbing practices in Brazil

Major carriers in Brazil do not explicitly adopt a hub-and-spoke structure as in the United States. In fact, no carrier in the country has a fortress hub like American Airlines' Dallas/Fort Worth, Northwest Airlines' Detroit Metropolitan or Delta Air Lines' Hartsfield-Jackson Atlanta International Airport. Identifying hubs in such market is far from trivial. Our starting point for assessing airport concentration of airlines' networks in Brazil was done employing a survey. This survey aimed to have a more structured idea of the organization of airport operations and on the amount of potential hubs in the carriers' networks.

We conducted an on-line survey with over 300 air transportation academics and professionals. As expected from most on-line surveys, the response rate was not very high as only 79 experts completed the questionnaire. The questionnaire consisted of two parts. In the first part, we asked for the best definition for a hub: "an airport for flight connections" or "a big airport". Over three-quarters of respondents picked up the first choice, with 18% answering both definitions, 3% stating the "big airport" option and only 1% answered none of these definitions. In the second part of the questionnaire, a list of the top 40 busiest Brazilian airports for domestic passenger traffic (data for May 2008) were presented and the respondents were asked to select: (1) those airports that they considered as a hub; (2) and those that, according to their opinion, should be a hub.

Fig. 3 presents the results for the second part of the survey, showing that the majority of respondents believe that only three airports are true hubs, actually: the "Top-2" domestic airports of Brasília (BSB) and São Paulo/Congonhas (CGH) – both named in over 90% of responses – and São Paulo/Guarulhos (GRU) – cited in over 70% of responses. While Brasília airport is more centrally located in geographical terms, Congonhas and Guarulhos serve the city of São Paulo, one of the largest metropolises in the world, and the heartbeat of the Brazilian economy. Guarulhos is the country's most important international airport with 8.21 million international passengers in 2006, accounting for 67.4% of the 12.18 million international air passengers in Brazil in the same year.

The result of three appointed hubs is significant to this proportion. Even if we considered "the majority" as being representative of more than up to 44% of respondents, we would still obtain the same result, as the fourth most frequently named airport, Tom Jobim/Galeão (in Rio de Janeiro) was considered as an actual hub by 43.5% of the participants in the cross section (see Fig. 3).

In terms of whether those airports should be or should not be hubs, again the majority of respondents stated only three airports: Brasília (over 85% of responses), Guarulhos (over 65%) and Tom Jobim/Galeão, the international airport in Rio de Janeiro with 2.15 million international passengers in 2006, and named in nearly 70% of responses. It is interesting to note that 78% of respondents stated that Congonhas, the central business district airport in São Paulo, should not be a hub. This clearly indicates that the busiest airport in the country (accounting for 18.46 million domestic passengers in 2006, which represents 20.5% of the total domestic passenger traffic for that year) should have its importance in the network reduced. Indeed, this ended up happening after the fatal accident in

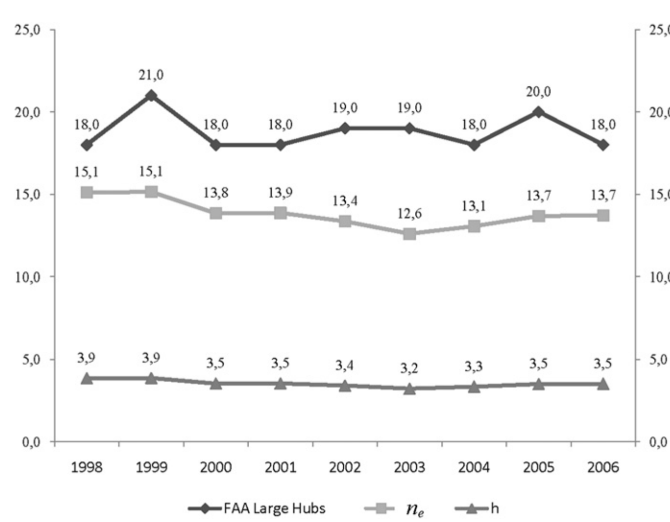

Fig. 5. Evolution of concentration according to alternative methods.

[1] We contrasted our results with the traditional Gini index approach and did not find significant changes in the main conclusion regarding the increase in airport concentration in Brazil during the period analyzed.

Table 1
Hub identification according to alternative methods.

Rank	Airport	Av. share 1998–2006 (%)	Specialists "actually a hub" (%)	FAA Lg hub (Av. share > l%)	n_e (rank < 14.1)	h (rank < 3.6)
1	São Paulo/Congonhas (CGH)	18.6	91.9	Yes	Yes	Yes
2	Brasília (BSB)	9.5	93.5	Yes	Yes	Yes
3	São Paulo Guarulhos (GRU)	8.8	72.6	Yes	Yes	Yes
4	Rio de Janeiro S. Dumont (SDU)	6.6	29.0	Yes	Yes	No
5	Rio de Janeiro T. Jobim (GIG)	5.9	43.5	Yes	Yes	No
6	Salvador (SSA)	4.9	27.4	Yes	Yes	No
7	Porto Alegre (POA)	4.0	12.9	Yes	Yes	No
8	Curitiba (CWB)	3.9	16.1	Yes	Yes	No
9	Recife (REC)	3.9	29.0	Yes	Yes	No
10	Belo Horizonte/Pampulha (PLU)	3.3	4.8	Yes	Yes	No
11	Fortaleza (FOR)	2.9	4.8	Yes	Yes	No
12	Manaus (MAO)	1.8	29.0	Yes	Yes	No
13	Belém (BEL)	1.8	11.3	Yes	Yes	No
14	Vitória (VIX)	1.8	0.0	Yes	Yes	No
15	Belo Horizonte/Confins (CFN)	1.6	11.3	Yes	No	No
16	Florianópolis (FLN)	1.6	1.6	Yes	No	No
17	Goiânia (GYN)	1.4	0.0	Yes	No	No
18	Natal (NAT)	1.4	4.8	Yes	No	No
19	Campinas (VCP)	1.1	4.8	Yes	No	No
20	Cuiabá (CGB)	1.0	3.2	Yes	No	No

2007 and the restrictions imposed by ANAC, the National Civil Aviation Agency, which limited the number of flights operated out of Congonhas and imposed a flight limited route to 1000 km (later extended to 1500 km). Hence, another reason for the concentration of traffic been considered as one of the factors for the accidents and the impacts on travel and tourism. In 2007, Congonhas accounted for 15.6% of the domestic passenger traffic, with this participation decreasing to 13.8% in the following year (Infraero, 2009).

The major factor for airlines choosing to operate in Congonhas is the location of the airport in the city of São Paulo. Situated in the Southeast area of São Paulo and near downtown, Congonhas is a better option for air passengers than Guarulhos, which is located 25 km from downtown and is neither served by train nor subway. Due to the chaotic traffic in the city of São Paulo, the journey to and from the airport takes at least 45 min. Additionally, because of the proximity of Congonhas to many HQ offices, the airport is usually associated with high demand generation from business travelers and with operations of air shuttle and regional flights.

3.2. *The FAA methodology and an HHI-based procedure for hub identification*

The US Federal Aviation Administration (FAA) uses a quite straightforward and simple methodology for the assessment and identification of the number of hubs within a network.[2] This method has been widely employed in the literature (Bazargan & Vasigh, 2003; Button, Lall, Stough, & Trice, 1999), classifying an airport according to its participation in terms of the total passenger traffic as follows: "small hubs" (0.05%–0.25%), "medium hubs" (0.25%–1%) and "large hubs" (more than 1% of passenger traffic). We applied the FAA's methodology to data collected from Infraero on domestic passenger traffic in Brazil between 1998 and 2006. With the FAA methodology, we identified 18 "large hubs" in Brazil for the year 2006. This is exactly the same number in 1998. On the other hand, the number of small hubs according to the FAA methodology decreased from 30 in 1998 to 21 in 2006, as presented in Fig. 4.

We found a considerable difference between the FAA method (Fig. 4) and the reality portrayed in our sample of responses from air transport experts (Fig. 3). Whereas in the survey we were able to pinpoint only three airports that were actually considered a "hub", with the FAA method, fifteen additional airports were identified as large hubs.

In order to proceed with the identification of the number of hubs from aggregate data on airport operations in Brazil, a simple procedure related to the Herfindahl–Hirschman Index (HHI) of concentration was employed. The HHI is a measure of the distribution of market size among firms, being equal to the summation of the square of firms' market shares ($HHI = \Sigma P_i^2$), where P_i is the participation of the i-firm in the market. Widely used in air transport markets to analyze the relationship between airfares and market concentration in the context of antitrust issues (Vasigh, Fleming, & Tacker, 2008), it is also recommended by several organizations, including the US Department of Justice (DoJ) and the US Federal Trade Commission (FTC) (Schimidt & Lima, 2002). The HHI is an attractive metric because of its straightforward correlation with the number of "effective" players. Indeed, the HHI may be regarded as the inverse of the number of firms in case all firms were of equal size. If, for example, the HHI in a certain market equals 0.1, this market would be as competitive as a market with 10 equally sized firms. Assuming symmetry, the inverse of HHI can then be regarded as the number of effective airports (n_e) in the market, which is the number of airports with significant market share in the system.[3] We can then interpret the inverse of HHI in the same spirit as the results from the FAA's methodology and therefore consider $n_e = 1/HHI$ as a proxy for the number of hubs within a network.

The HHI was primarily conceived to be within the range 0–1. However, in the case of airports it ranges only from 0 to 0.5 as one take-off always implies a landing at another airport. Hence, any given airport cannot have more than fifty percent of aircraft movements in a given network. The maximum concentration of an air transportation system with n airports occurs when only one hub has 50% of the market and the remaining traffic is equally shared by the spokes. In such a case, the concentration level HHI(h,n), with h

[2] http://www.faa.gov/airports_airtraffic/airports/planning_capacity/passenger_allcargo_stats/categories/.

[3] We agree that the assumption that the hubs are perfectly symmetric may be regarded as rather strong. On the other hand, however, it is important to note that our model aims at separating airports in only two groups: hub airports and spoke airports. The symmetry approach applies within a group, but, of course, not between groups. More disaggregated classifications may be performed, for example, by applying the same method (or the FAA's) for each subgroup. We think that the hub airports identified by our approach are not considerable asymmetric.

being the number of hubs, is HHI(1,n) = 0.25n/(n − 1). With h symmetric hubs, the equivalent maximum level of concentration would then be HHI(h,n) = 0.25n/(hn − h).

Our HHI-related procedure uses HHI(h,n) as a reference for hub identification. By solving HHI(h,n) for h it is possible to obtain $h = 0.5\{n - (n^2 - n/\mathrm{HHI})^{-1/2}\}$. We can consider this expression as another proxy for the number of hubs within a given network. It has the advantage of being effectively developed from the HS network structure and being related to a well-known concentration index such as the HHI. In this case, h is directly related to the number of effective participants (ne_e): $h = 0.5\{n - (n^2 - n\, n_e)^{-1/2}\}$. On the other hand, it must be considered only as an approximation to the effective number of hubs, as it implies strong symmetry within and between the groups of hubs and spokes. We may interpret h as the number of hubs that a system of n airports would have in case there were h equally sized hubs with maximum hub-and-spoke operations – that is, with all spoke traffic being channeled through the existing hubs[4] (see Appendix for details on the calculation).

4. Results

We made use of the three above-mentioned approaches in order to quantify the number of hubs in the domestic air transportation system in Brazil. The available data consisted of total domestic enplanements disaggregated by airport in Brazil. Enplanements include all domestic connecting and non-connecting boardings on scheduled flights. Passenger boarding data were aggregated for a full calendar year. The sample period is 1998–2006, with the sources being the Statistical Yearbook of Department of Civil Aviation (DAC) and Infraero's internal reports. DAC is the former airline regulation agency in Brazil, which was substituted by ANAC, and Infraero is the state-owned airport operator, which manages the most important airports within the country, comprising 97% of total domestic passenger traffic. DAC data were disaggregated by pairs of airports.

Fig. 5 presents the results of the application of the methods of hub identification to the Brazilian data. It contains the number of hubs according to the FAA methodology (''FAA Large Hubs''), the number of effective airports from the inverse of system wide HHI (n_e) and the number of hubs according to our proposed HHI-related metric, h.

Fig. 5 shows the results obtained from our metric are the closest to the opinions from the cross section of specialists described earlier. Indeed, h is always around 3.5, indicating the number of hubs lower than four. This is precisely the same result obtained from the *on-line* survey. In contrast, both FAA Large Hubs and n_e tend to indicate a number of hubs that is higher than ten. For these results to be in accordance with most specialists' opinion we would have to consider a ''majority'' in the panel as being represented by less than fifteen percent of the cross section, which would clearly not be an adequate procedure.

In spite of these caveats, by analyzing the path of our suggested metric across time, it is possible to observe that, consistent with the increase in the concentration ratio C-2 presented in Fig. 2, there was a relevant increase in the concentration levels. Indeed, h decreased from almost four hubs in 1998 to slightly above three in 2003. In particular, that same year was marked by a code share agreement between the two major legacy carriers in Brazil (Varig and TAM), in order to restructure their networks and to strengthen their market positions to better compete with the low-cost newcomer Gol Airlines. We believe that the result of increase in concentration captured by HHI-based approach reinforces the idea that domestic air transportation in Brazil was subject to higher concentration of networks in few airports towards a consolidation of hub-and-spoke operations by carriers. This result, combined with the notable augment of total domestic enplanements in recent years (see Fig. 2), increased the pressure on existing airport infrastructure, especially in terms of congestion in major airports within the country (Endres, 2007; Knibb, 2007; TCU, 2006).

Finally, we performed an exercise of hub identification within the domestic air transportation system in Brazil according to the alternative methods employed. Table 1 presents the results, where the average enplanement in the sample period 1998–2006 was considered.

It is possible to note that all four methods (survey of specialists, FAA Large Hub Methodology, Number of Effective participants, n_e, and our suggested h metric) agree that São Paulo/Congonhas (CGH), Brasília (BSB) and São Paulo/Guarulhos (GRU) are actual domestic hubs in Brazil. The City of Rio de Janeiro's airports Santos Dumont (SDU) and Tom Jobim/Galeão (GIG), however, are identified as ''hubs'' only by the FAA methodology and the n_e metric. This also happens to Salvador (SSA), Porto Alegre (POA), Curitiba (CWB), Recife (REC), Belo Horizonte/Pampulha (PLU), Fortaleza (FOR), Manaus (MAO), Belém (BEL) and Vitória (VIX). The remaining airports are considered ''hubs'' only by the FAA methodology. Results from Table 1 are reasonably stable over the period 1998–2006.

5. Discussion and conclusion

Air traffic concentration in Brazil contributed to a series of events that have resulted in uncertainty and lack of confidence in the air transport system. From the two fatal accidents killing over 350 people to the financial costs of flight cancellations, delays and all sorts of impacts on various types of business, including tourism. As pointed out by Gedeon (2007, p. 18) ''the system was working in an uncoordinated manner and Infraero was prioritizing the building of luxurious terminals instead of focusing on the safety of the runways and airport communication systems''.

Although our model still needs to be tested in other countries and networks, what is particularly important in Brazil and many other developing countries around the world is to develop mechanisms to constantly monitor their air transport systems. A website where indicators are presented in a dashboard style, similar to what has been proposed by Park and Jamieson (2009) for tourism in Hawaii, can be a useful tool to make all major stakeholders involved with air transportation aware of the current scenario. This might include, for example, the degree of concentration in a given network, among other data. The most important thing is the way that this information will be presented to make it easier to be read by non-experts in air transportation, such as those involved with tourism organizations and business.

It is critical to emphasize, however, that although our suggested metric had a favorable result in the application to Brazilian data, we cannot consider this as a proper validation of the proposed method. It may be suggestive that the model is, in this particular case, much more effective in the identification of hubs than the FAA's methodology or the inverse of HHI. Nevertheless, we believe that further research on this issue should be carried out. In particular, we think that the mathematical procedure to adjust the traditional HHI metric should account for the asymmetries among hubs and spokes. Additionally, such an improved index should account for hybrid network structures, partially formed by Hub-and-spoke and

[4] An alternative and very straightforward procedure to obtain h is to rank all airports in a descendent order of size and to accumulate the market shares until 50%. The first airports would be ''hubs'' and the remaining airports would be spokes. Note that we impose a pure hub-and-spoke system in order to obtain h.

Point-to-Point operations. A comparison with other indexes found in the literature, such as the "NC-Gini" (Burghouwt et al., 2003) should be attempted.

This mechanism would be particularly useful in a situation like the current one in Brazil, where there is a lot of discussion and initiatives happening. One major discussion is the privatization of some airports, particularly Campinas (VCP – see Table 1), near São Paulo, and Tom Jobim/Galeão (GIG) in Rio de Janeiro. Both airports have large underused infrastructures and are located in regions with large generating passenger traffic and appealing to business and leisure tourists. In addition, expanding air traffic to these airports might be a way to decrease the concentration of flights in Congonhas (CGH), Guarulhos (GRU) and Santos Dumont (SDU), which according to Table 1 are among the top four airports in terms of concentration of flights in the period 1998–2006.

It is also expected that because of the network concentration more and more regional flights will be offered in Brazil, particularly by-passing the major hubs and offering direct flights between small and medium size cities. In fact, at the end of 2008, the former CEO and founder of JetBlue, David Neeleman, launched a new airline in Brazil called Azul, Portuguese for Blue. Flying out of Campinas (VCP), the airline is operating 118-seat Embraer E-195s and 106-seat E-190s (Kirby, 2009).

If tourism is really going to become a major economic activity in Brazil, it is necessary that good air transport infrastructure be in place, supported by a regulatory environment where airlines and air traffic control do not operate under congested bottlenecks. The terrible consequences of the two fatal accidents were felt not only by the victims and their families, but also by a wide range of tourism activities and destinations that struggled to survive during the months where air transport system was not reliable. Tourists were scared as a consequence of an unreliable system, not only in terms of safety, but also of punctuality (Panosso Netto & Trigo, 2009). Investments should be made not only to those visible parts of the infrastructure, such as airport terminals, but also in areas that are crucial to safety and functionality of the system. The quote by Gedeon presented at the beginning of this section, exemplifies the mentality of many politicians that advocate for tourism in their state or city, with investments made at one end of the system, usually in the destination region. They forget that a vacation or business trip begins at the major generating markets and that if investments are not distributed throughout the whole transportation system, tourists will not arrive.

In 2014, Brazil will host the World Cup Soccer with ten different cities hosting the games. This will be the most important event ever happened in the country which will promote it to millions of people throughout the world. Air transport will be the major way for teams, fans and media to travel from one place to another. The examples of the two fatal accidents and the follow-up events are a major lesson in terms of how important is to plan and monitor, among other issues, the concentration and the infrastructure of a network. We hope that the discussion generated in this article and the model proposed here can contribute not only to broaden the understanding of the importance of having a reliable tool to measure the number of hubs in a given air transport network, but also to highlight its impact on tourism.

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Appendix

The Herfindahl–Hirschman Index of concentration of a given network with n airports is defined in the following way:

$$\mathrm{HHI}(n) \equiv \sum_{i=1}^{n} s_i^2, \tag{1}$$

in which S_i is the share of airport i. It is clear that $\sum_{i=1}^{n} s_i = 1$. Suppose now that airports may be classified into two categories: hub airports and spoke airports. By definition, a hub is an airport in which all traffic is funneled through. With this restriction, hubs concentrate 50% of all enplanements + deplanements, with spokes generating the remaining 50% enplanements + deplanements. There are h hubs and $n - h$ spokes. We then have:

$$\mathrm{HHI}(n,h) \equiv \sum_{i=1}^{n} s_{hi}^2 + \sum_{j=1}^{n-h} s_{sj}^2, \tag{2}$$

in which HHI(n,h) is the concentration level of a network with n airports, h of them being hubs, S_{hi} is the share of hub i and S_{sj} is the share of spoke j. Clearly, we have $\sum_{i=1}^{n} s_{hi} \sum_{j=1}^{n} s_{sj} = 1$. By imposing symmetry and making use of the definition of hubs, we then have:

$$\mathrm{HHI} \equiv \mathrm{HHI}(n,h) = \left(\tfrac{0.5}{h}\right)^2 h + \left(\tfrac{0.5}{n-h}\right)^2 (n-h) = \frac{0.25}{h} + \frac{0.25}{n-h} \\ \mathrm{HHI} = \tfrac{0.25n}{h(n-h)} \tag{3}$$

In the maximum possible concentration situation, there is only one hub with 50% of traffic. In such situation we have:

$$\mathrm{HHI}^* \equiv \mathrm{HHI}(n,1) = \frac{0.25n}{n-1} \tag{4}$$

If we divide (3) by (4) we have:

$$\frac{\mathrm{HHI}(n,h)}{\mathrm{HHI}(n,1)} = \frac{\mathrm{HHI}}{\mathrm{HHI}^*} = \frac{0.25n}{h(n-h)}\frac{n-1}{0.25n} = \frac{n-1}{h(n-h)} \tag{5}$$

and,

$$h(n-h)\mathrm{HHI} = (n-1)\mathrm{HHI}^* \tag{6}$$

$$(-\mathrm{HHI})h^2 + (n\mathrm{HHI})h + (1-n)\mathrm{HHI}^* = 0 \tag{7}$$

By solving the quadratic equation we then have:

$$h = \frac{n}{2} \pm \sqrt{\frac{n^2}{4} - (n-1)\frac{\mathrm{HHI}^*}{\mathrm{HHI}}} \tag{8}$$

By substituting (4) in (8) we finally have:

$$h = \frac{n}{2} \pm \sqrt{\frac{n^2}{4} - \frac{0.25n}{\mathrm{HHI}}} \tag{9}$$

and then,

$$h = \frac{1}{2}\left(n \pm \sqrt{n^2 - n_e n}\right), n_e = \frac{1}{\mathrm{HHI}} \tag{10}$$

References

Alderighi, M., Cento, A., Nijkamp, P., & Rietveld, P. (2005). Network competition – the coexistence of hub-and-spoke and point-to-point systems. *Journal of Air Transport Management, 11*(5), 328–334.

Babcock, B. A. (Ed.). (2002). *Making sense of cities: A geographical survey*. London: Oxford University Press.
Bazargan, M., & Vasigh, B. (2003). Size versus efficiency: a case study of US commercial airports. *Journal of Air Transport Management, 9*(3), 187–193.
Bettini, H. F. A. J., & Oliveira, A. V. M. (2008). Airline capacity setting after re-regulation: the Brazilian case in the early 2000s. *Journal of Air Transport Management, 14*(6), 289–292.
Brancatelli, R. (2007). País Perdeu R$ 3 Bi Com Crise Aérea. *O Estado de São Paulo, September 30*. São Paulo.
Burghouwt, G. (2007). *Airline network development in Europe and its implications for airport planning*. Hampshire: Ashgate.
Burghouwt, G., Hakfoort, J., & Ritsema van Eck, J. (2003). The spatial configuration of airline networks in Europe. *Journal of Air Transport Management, 9*(5), 309–323.
Button, K. (2002). Debunking some common myths about airport hubs. *Journal of Air Transport Management, 8*(3), 177–188.
Button, K., Haynes, K., & Stough, R. (1998). *Flying into the future: Air transport policy in the European union*. Cheltenham: Edward Elgar Publishing.
Button, K., Lall, S., Stough, R., & Trice, M. (1999). High-technology employment and hub airports. *Journal of Air Transport Management, 5*(1), 53–59.
Endres, G. (2007). Crisis control: troubled year highlights problems in Brazil's air transport market. *Flight International*. (Flightglobal).
Folha, de S. Paulo (2006a). *78% dos Viajantes Estão Apreensivos, Dizem Operadoras de Turismo*. São Paulo: Folha de S. Paulo.
Folha, de S. Paulo (2006b). *Atrasos Atingem Vôos nos Principais Aeroportos do País*. São Paulo: Folha de S. Paulo.
G1. (2006). *Crise Aérea Faz Venda de Pacotes Turísticos Cair 50%*. Rio de Janeiro: Globo.com.
Gedeon, E. (2007). Coping with crisis: Brazil's air transportation system. *Airline Fleet and Network Management*.
Hoffman, J. & Voss, W. (2000). Analytical identification of airport and airspace capacity constrains. 3rd USA/Europe Air Traffic Management R&D Seminar Napoli, June 2000.
Horner, M. W., & O'Kelly, M. E. (2001). Embedding economies of scale concepts for hub network design. *Journal of Transport Geography, 9*(4), 255–265.
Huber, H. (2008). Comparing spatial concentration and assessing relative market structure in air traffic. *Journal of Air Transport Management* 1–11.
Infraero. (2009). *Movimento nos Aeroportos*. Brasilia: Infraero.
Kanafani, A., & Ghobrial, A. A. (1985). Airline hubbing: some implications for airport economics. *Transportation Research Part A, 19*(1), 15–27.
Kirby, M. (2009). Neeleman's Azul takes flight. *Airline Business*.
Knibb, D. (2007). Brazil's bottleneck to change. *Airline Business*. (Flight Global).
Lohmann, G., Albers, S., Koch, B., & Pavlovich, K. (2009). From hub to tourist destination – an explorative study of Singapore and Dubai's aviation-based transformation. *Journal of Air Transport Management, 15*(5), 205–211.
Martín, J. C., & Voltes-Dorta, A. (2009). A note on how to measure hubbing practices in airline networks. *Transportation Research Part E: Logistics and Transportation Review, 45*(1), 250–254.
Nero, G. (1999). A note on the competitive advantage of large hub-and-spoke networks. *Transportation Research Part E: Logistics and Transportation Review, 35*(4), 225–239.
O'Kelly, M. E. (1998). A geographer's analysis of hub-and-spoke networks. *Journal of Transport Geography, 6*(3), 171–186.
Oliveira, A. V. M., & Salgado, L. H. (2006). Reforma Regulatória E Bem-Estar No Transporte Aéreo Brasileiro: E Se a Flexibilização dos Anos 1990 Não Tivesse Ocorrido?. In *Acervo Científico do Núcleo de Estudos em Competição e Regulação do Transporte Aéreo* São José dos Campos, SP, Brazil: NECTAR.
Oum, T. H., Zhang, A., & Zhang, Y. (1995). Airline network rivalry. *Journal of Economics, 18*(4a), 836–857.
Panosso Netto, A., & Trigo, L. G. G. (2009). *Cenários do Turismo Brasileiro*. São Paulo: Aleph.
Park, S.-Y., & Jamieson, W. (2009). Developing a tourism destination monitoring system: a case of the Hawaii tourism dashboard. *Asia Pacific Journal of Tourism Research, 14*(1), 39–57.
Pels, E. (2001). A note on airline alliances. *Journal of Air Transport Management, 7*(1), 3–7.
Reynolds-Feighan, A. (2001). Traffic distribution in low-cost and full-service carrier networks in the US air transportation market. *Journal of Air Transport Management, 7*(5), 265–275.
Rodrigue, J.-P., Comtois, C., & Slack, B. (2006). *The geography of transport systems*. New York: Routledge.
Schimidt, C. A., & Lima, M. A. (2002). In Ministério da Fazenda. (Ed.), *Índices de Concentração*. Brasília.
Shaw, S. (1993). *Airline marketing & management*. London: Pitman Publishing.
TCU. (2006). *Relatório de Levantamento de Auditoria No Sistema de Controle do Tráfego Aéreo*. Brasília: Brazilian Supreme Audit Institution (TCU).
Vasigh, B., Fleming, K., & Tacker, T. (2008). *Introduction to air transport economics*. Hampshire: Ashgate.