1. Introduction

The moving of people and goods is one of the most challenging issues in modern days. The spreading of the globalization process increases the need for exchanging knowledge and technology amongst countries, regardless of the distance that needs to be transposed. The international features of the global markets increases the role of logistics, especially in aspects related to transportation, quality and viability.

In this scenario, the Air Transportation has a strong importance. The expansion of the manufacturing of high technology products, the necessity for cutting costs in the production chain, especially those related to labor costs, and the enhancement of productive systems such as JIT (Just in Time), make the logistics related to the air freight transportation crucial for the competitiveness.

At the same time, the "cultural borders" are almost disappearing, making the role of distance much less important than in previous decades. Nowadays, it is possible to travel medium distances by plane, for instance 500 km, in less than half an hour, for a reasonable price. This fact has increased the competitiveness of this mode in comparison to other modes, especially the road transportation.

Cost reduction has become possible because the air companies managed to cut out their operational costs, and started to use fuel efficient aircrafts, diminishing the overall costs and consequently the final price of the ticket. Another interesting strategy that has helped the air companies to be more competitive was the adoption of the hub-and-spoke network configuration.

According to Fulco (2006), the word *hub* can be described as a *center of importance* or *interest*. The word *spoke* can be defined as a *radius*, or *arcs*. Therefore, the hub-and-spoke system can be interpreted as a *relevant center* connected to many nodes through *radius* or *arcs*. This strategy optimizes the number of linkages in the network, diminishing the overall costs.

It is known that all around the world the aviation industry is one of the most difficult businesses to manage. The complexity of the operations, the huge fixed costs involved and the volatility of the market are some features that make this industry one with the lowest profit rates, turning to be a hard challenge for the planners and managers involved.

1.1 Problem Statement

The main objective of this Dissertation is, by making use of Operational Research (OR) techniques, to formulate mathematical models for hub location problems in the South American continent, with focus in Brazil, and explores the results. The Latin America region has been showing impressive growth rates in the last years, for both passengers and freight, and all forecasts predict that such growth rates will be maintained.

According to the McKinsey report (2010), the Brazilian air passenger market has been processing more than 50 million trips per year, a number that grew by an impressive rate of 10% per year between 2003 and 2008. In the second semester of 2009, despite the global financial crisis, there was a strong demand recovery in the domestic air services, generating a cumulative annual traffic at the same level of 2008.

In the Ipea report (2010) it is mentioned that Brazil has become one of the emerging countries around the world, with the greatest potential for development in the air transportation sector, mainly due to a favorable combination of several factors: i) the size of the continental territory; ii) high social and geographical mobility of its population; iii) the fast displacement of the economic boundaries; iv) the competitive insertion in the global markets on a vast range of goods and services; and v) the long-term monetary stability, with the consequent increase in the purchasing power of the consumers.

The big issue behind this expansion is the lack of airport infrastructure in the majority of the South American countries. Especially in Brazil, the focus of this dissertation, the busiest airports already face huge problems of congestion and most of them do not have physical space available in their vicinities for an infrastructure expansion. According to the McKinsey report (2010), the airport infrastructure has not grown at the pace of the demand. Out of the 20 major domestic airports, 13 have already bottlenecks in passenger terminals, with a consequent reduction in the service level to the users. The critical case is the city of Sao Paulo, the main hub of the country, which concentrates about 25% of total traffic. The Congonhas - SP airport, the busiest one for domestic flights in Brazil, was the first one in the country to present limitation on the availability of slots for

new takeoffs and landings, recently followed by the airport of Guarulhos – SP, on the same limitation.

In the Ipea report (2010) it is emphasized that the evolution of this market is colliding with obstacles and bottlenecks in the institutional, legal, infrastructural and operational issues. Indeed, the rapid growth of demand was not accompanied by: i) an adequate long-term planning for the civil aviation system as a whole; ii) consistent public policies, iii) legal and regulatory framework in accordance with the new competitive environment; and iv) the overcoming of the notorious shortcomings in airport and aeronautical infrastructures.

These prospects may get much worse with the announcement made by the International Olympic Committee that the city of Rio de Janeiro was chosen to host the Olympic Games in 2016. Before that, FIFA had already announced that Brazil will host the World Cup in 2014. Despite all the celebrations followed by these announcements, the authorities have a lot of work to overcome the deficiencies, especially regarding the transportation infrastructure.

Using *Operational Research* techniques, this Dissertation aims to explore real applications on the air transport sector. The main location models for the hub-and-spoke strategy will be shown and two new problems will be presented. The first problem considers the South American continent and takes into consideration a network with 50 airports, being 41 in Brazil and nine in other countries of South America. Some assumptions have to be introduced, especially imposed by the lack of appropriated data. The main objective of this first modeling and application is to identify major and mini hubs for a hypothetical passenger market in South America.

The second problem searches for an optimal solution using OR techniques for bigger instances of data. It takes into account the Brazilian Air Transportation market for passengers, considering the data for 135 airports, and proposes a new methodology – which is divided into two phases - for solving this type of problem. The results obtained appear quite promising.

1.2 Data Limitation

In real applications, the observation of the flow matrix amongst nodes, usually denoted by W_{ij}, is a major difficult task. The correct application of a location model is strongly dependent of the correct knowledge of the flow matrix. The origin of the problem is that the private companies treat this data as confidential and strategic, and the government owned regulation agencies, INFRAERO[1] and ANAC[2], just collect transport data amongst airports, not the origin/destination matrix.

For the first modeling and application, 41 Brazilian airports were considered and nine airports in the other countries of South America. In Brazil, the most notable airports in terms of passenger movements have been taken. For the other countries of South America only the main airports located in the Capitals of the nine countries were considered.

Through the Annual Statistics of Air Transportation - 2007, published by ANAC, it was possible to determine the passenger flow matrix amongst the 41 Brazilian airports. The flow amongst the nine other South American airports was obtained using a database published by CLAC (Latin America Commission of Civil Aviation) regarding the year 2007. The flow between these two data sets, from/to the 41 Brazilian airports to/from the nine other South American airports had to be estimated through a gravitational model. The methodology used is shown in section 6.2.

[1] INFRAERO is a public company established in 1972 and responsible for the operation of 67 airports, 33 cargo logistics terminals in the country. It is subordinated to the Ministry of Defense.

[2] ANAC is a civil organization agency established in 2005 and also subordinated to the Ministry of Defense, with administrative and financial independence and responsible for technical and economical regulation of the sector.

1.3 Positioning of the Research in the Scientific and Technological Context

The economic expansion in many countries around the world (mainly in those called emergent) and the widespread of the globalization process has brought significant consequences for the air transport industry. Air transportation of cargo and passengers in Brazil has been showing remarkable growth rates. In 2007, in relation to 2006, demand for passengers grew approximately 12%, with companies increasing their offers of seats by 16.3% (ANAC-2007). With the trend of the Brazilian economy towards stabilization and the relative increase in the purchasing power of the population in general, combined with the increasing participation of the low cost/low fare companies, air transportation has become available to large sectors of the population. More recent data informs that in Brazil, regular flight have increased 25.7% in July 2009 and 21.5% in August 2009, in comparison to the same period of 2008 (Takar and Fariello-2009).

These carriers have pushed the competition among themselves, and with other modes of transportation, in particular the road transportation. This type of carrier operates with a modern and standardized fleet, making possible an efficient cost of operation and high rates of productivity. These carriers configure their networks in a point-to-point model, focusing their operations in the secondary airports and offering a *no-frill*[3] service. Such policies reduce considerably the airfares and make the air transportation service available to most of the population.

The planning management of all tasks involved is not simple. The definition of the number of aircrafts to serve a set of cities, the frequency of flights, the route planning, all of the demand forecasts and the management of all costs involved are difficult tasks. At the same time, many airports have been facing lots of problems in terms of physical infrastructure. The poor infrastructure is affected by outdated passenger and freight terminals, poor road, rail, and

[3] In order to keep the fares low, the airlines have eliminated the non – essential services, such as complimentary drinks, snacks, entertainment systems, etc.

subway accesses, limited number of runways and all the necessary technology to handle the air space control.

It is well known that the investments in science and technology have been increasing considerably in the last decades. An example is the announcement made by the President of the United States of America, in April 2009, in the middle of a huge financial crisis, for doubling the investments in Science and Technology in his country.

In the next decade, Brazil will host two of the most important events in the world: the World Cup in 2014 and the Olympic Games (in the city of Rio de Janeiro). Huge investments need to be done, especially in infrastructure and transportation. In this context, the proposals developed in this Dissertation will show the opportunity for contributing with a real application and a deep analysis of the Brazilian air transportation system.

It is well known that the Brazilian airport infrastructure has several problems: congestion, deficiency in physical infrastructure (such as passenger and freight terminals), poor integration for different types of modes and lack of specialized labor to work in the Air Traffic Control (ATC), to name some of them. To cope with it in a sustainable way, the authorities must be aware about this imminent increase in the demand and the necessity of these investments.

The increasing utilization of the hub-and-spoke configuration by the carriers has portrayed the system's weakness. This structure of configuration concentrates the operations in some major airports, called hubs, and increases the flight frequencies and the level of accessibility of some points, especially those that do not have a high level of demand. As a consequence, there is a reduction in the unit transportation costs between *hubs*, creating direct benefits to the users.

This Dissertation deals with a much known strategy for the configuration of networks in the air transportation industry called hub-and-spoke, which will be later described and detailed. Essentially, this type of network aims to concentrate the flows into hub airports, channeling them to the peripheral points, called spokes. In this way, the number of links used in the network decreases, while economies of scale experienced in the linkages amongst hubs reduce costs, pushing down the overall costs of the network.

Since 1986, when O`Kelly (1986) formulated the first location model for hub-and-spoke networks, there is plenty of research in this field. Studies in management science, geography, logistics, transport engineering and computation are common, amongst others. With all the improvements already achieved in these areas, the subject still has a vast area to be explored.

1.4 The Description of the Objectives of the Research

The objectives of this Research can be divided in two segments: the elaboration of the models and the analysis of the results. Both are difficult tasks, especially because of the issues and specific problems to be considered for Brazil and the South American continent. For the first segment all of these problems and issues need to be incorporated into the model. Issues such as congestion, airport capacities, the decision of consolidating flow or not (through the allowance of sending a direct flow or not) and the geographical areas that can be served by a facility have to be carefully analyzed.

In the second segment, the results are analyzed. The location of the hub airports chosen by the models and their geographical issues are discussed. The flow patterns were plotted using the transportation software TRANSCAD 4.5 and the main trunks are shown, with their features being analyzed. The main objectives of the analysis are: to create a methodology to assess the Brazilian airport infrastructure and the possibility to suggest to the governmental authorities some improvements given the present configuration, if it is arranged in the way that is stated, followed by a discussion and explanation of the proposals.

1.5 Organization of the Dissertation

This Dissertation is organized as follows. In the next two sections the thesis positioning in the scientific and technologic context is presented, followed by its description and objectives. In Section 2 the air transportation features are presented, based on statistical data and trends published by some important entities in the field. In Section 3, a literature review is shown, covering some issues in the location theory and followed by a presentation of the main concepts and models in the hub-and-spoke strategy. In Section 4, the two case studies are

presented, including the methodology used to obtain the data, the mathematical formulations proposed followed by the discussion of the results. Section 5, entitled as Final Conclusions, is divided into three sub-section, which will cover conclusion about the results achieved, the main contributions of the Dissertation and the suggestions for future studies.