5. Final Conclusions

5.1 Conclusion

After the deregulation of the air passenger in the American market at the end of the 70`s, the configuration of networks through the hub-and-spoke strategy started to spread out in different areas of the industry. Especially for the Air Transportation, this fact became extremely useful. Well known as an industry with a very low profit margin, the managers of this segment need to be wise in thinking of new solutions that usually rely on maximization of profits and/or minimization of costs.

The operation's optimization of an airline is not an easy task. For maximizing profits, they need to keep aircraft in the air for most of the time, at the same time that high indices of frequencies and load factor measurements are achieved. Before the deregulation of the air passenger in the American market, the airlines networks were basically structured in a linear manner, which used to make harder the profit's maximization process. The occurrence of two facts has helped a favorable approach to face the challenges, such as: the achievement of gains in economies of scale in the operations and the minimization of costs by diminishing the number of the routes in the network.

Despite some carriers operating networks based on linear linkages, especially those called low-cost/low fare, it is difficult to visualize that a carrier is able to obtain success without configuring their networks using the hub-and-spoke strategy. The core business of the low cost/low fare companies, which was not covered in this Dissertation, operate linear networks with fuel efficient aircrafts and no frill services, searching for offering high frequencies in direct linkages that are not covered by the hub-and-spoke carriers.

Especially regarding the economies of scale achieved in the linkages between hubs, most of the air carriers around the world operate larger aircrafts in these routes in order to obtain economies of scale. In the United States, for instance, mainly due to the continental dimensions of the country, the bigger carriers such as United Airlines, American Airlines, Delta, US Airways and Continental Airlines use domestic hubs along the country and make use of trunk linkages to enjoy these gains.

In Brazil, the airlines do not operate larger aircrafts in the trunk routes. The Brazilian Air passenger market has two main carriers that concentrate more than 80% of the total domestic passenger traffic. These two carriers, GOL and TAM, operate with a standardized fleet in the domestic market. GOL operates with Boeings 737 (700 and 800) and TAM operates with Airbus (A-319 and A320). Even though they configure their networks in a hub-and-spoke strategy, both carriers use the same aircrafts to make the linkages from/to spoke airports to/from hub airports. This type of operation is closer to another well-known strategy: the use of major and mini hubs. This technique, as already shown and explained in this study, seems to better fit into the strategy that the Brazilian carriers have chosen to operate. Mainly based on this fact, this pattern of network configuration was chosen to be used in the development and application of the mathematical model in the Case Study A.

In addition to the traditional features that are typical for the major/mini hub location problems, an interesting characteristic was added to the modeling: the allowance for direct linkages. In Brazil, there are a considerable number of pairs of cities that have sufficient demand that would avoid extra stopping at hub airports, which is the case of the linkage amongst the cities of Rio, Brasilia and Sao Paulo, for instance.

Another important fact that contributed to achieve the results for the real case application in the Case Study A was the hypothetical consideration of an unique market in South America. Actually, there were some limitations in the determination of the data amongst the South American cities (excluding Brazil) and the Brazilian cities. It was also mitigated through the application of a gravitational model to estimate these flows. In total, the number of airports used in the Case Study A was 50, which was divided into 41 Brazilian airports and nine in the other countries of South America.

For the Case Study A, four experiments were made. The sensitivity analysis has focused on the variance of some parameters used to define the radius service for the mini hubs. As expected, the number of airports allocated to a mini-hub was increasing at the same time that these radius service parameters were increasing as well. All the four solutions presented interesting singularities amongst them.

Regarding the location of the two major hubs, the airport of Congonhas (CGH)-SP, in the city of Sao Paulo, was pointed out in the optimal solution to be one of them. There is an evident explanation relying basically on two issues: the economic importance of the city of Sao Paulo, not simply for Brazil, but for the South American continent as a whole. The other is the passenger air traffic in Sao Paulo, which is very huge, and consolidates the city as the main Brazilian pole for generating and attracting passengers. With a metropolitan population of approximate 20 million people and presenting significant contributions to the national GDP (Gross Domestic Product), the city also enjoys a strategic geographic location in relation to the other main economic centers in Brazil and in South-America.

In three of the four experiments made in the Case Study A, the city of Teresina, in the Brazilian state of Piaui - northeast region of the country - was chosen to be a major hub. For the last experiment, the airport chosen to be a major hub is located in the city of Sao Luis, in the Brazilian state of Maranhao - also in the northeast region of the country. These two cities are close to each other in terms of aerial distance. The fact that in the four experiments, there was at least one northeastern city chosen by the model to be a major hub, shows a significant and important trend for this Brazilian region to host an important airport.

Some similarities in the solutions achieved for the four experiments were also found for the mini hubs. Again, two regions had mini hubs chosen in all of the four experiments: the central north and the northeast regions. In three of the four experiments, the city of Brasilia – the federal capital of Brazil – was chosen to be a mini hub. In the other experiment, the city of Goiania – in the Brazilian state of Goias – was chosen to be a mini-hub. The northeastern cities chosen to be mini hubs were Salvador – in the Brazilian state of Bahia – and Maceio – in the Brazilian state of Alagoas. When the service radius distance value was changed, the number of airports assigned to the mini hubs has increased, as expected. The third mini hub in all of the four experiments was located in the northwest region of the South American continent: two of the four experiments pointed out the city of Bogota, in Colombia, to act as a mini hub and the other two experiments found Quito, in Ecuador, to be a mini hub.

In the Case Study B, where just the Brazilian air passenger traffic was taken into consideration, real and practical results were also found. The proposed methodology, which consists of solving the problem in two phases, enabled a visualization of the pattern of the flows in the whole country for a network operating in a hub-and-spoke strategy with 3 hubs. The three airports chosen to be hubs were: Brasilia-DF, Guarulhos-SP and Maceio-AL. In this modeling, direct linkages were also allowed for a trip through a pre-set threshold, which has reduced the volume of passengers transported amongst hubs, with good consequences for avoiding congestion on the hub sites.

Some interesting issues can be explored if an analysis considering the results obtained in the two Case Studies is made. Especially taking a Geographic's point of view, and considering the division into the five sub-regions proposed in the Case Study A, the only region that did not have any hub (a major hub or a mini hub – in the Case Study A or just a hub – in the Case Study B) was the south region, even though some important cities in terms of some aspects - such as demography, economy, and history - were located at this region. This can be partially explained by the strong influence that the southeast region has over the rest of the regions in the study, and the constrained imposed by the model to locate a limited amount of major and mini hubs. The same was noticed in the Case Study B. Again, the south region was not contemplated with a hub airport. The majority of flows originated and destined to the south cities were routed through Sao Paulo.

With the allowance of direct linkages and multiple assignments, the shape of the flows amongst hubs is another interesting feature noticed in the results obtained in the Case Study B. As can be noticed in the pattern of flows in the study made by O'Kelly (1998), the hubs are not set close to each other and the flows amongst them are quite dense. In the Case Study B, this also happens but especially one linkage did not reach a flow with a dense shape: the one between the airport of Brasilia and the airport of Maceio. The linkage between the cities of Rio de Janeiro and Sao Paulo is much denser than this one.

Tough times are expected in a near future for the Brazilian air transportation passenger market. The country has been showing exciting growth rates in the economy, which directly contributes for the increasing in the demand

for air travels. Nevertheless, the actual infrastructure available is not enough to cope the increasing demand and all the investments predicted by the enterprise responsible are not sufficient. The Brazilian main airports operate above their capacities and already present serious congestion problems.

The two Case Studies in this Dissertation aimed to make two real applications, using different types of modeling, in the South American Continent and in Brazil – with the allowance of direct linkages in both models. The results confirmed the trend for the city of Sao Paulo, in the southeast region of the country, to host a hub airport and the northeast region, with the cities of Teresina-PI, Sao Luis-MA, Salvador-BA and Maceio-AL, appearing as potential sites for hosting airport hubs – depending on the model type used.

5.2 Main Contributions

This study has given important contributions for the strategies involved in the configuration of air transportation networks. Two real case applications were made for the South American air passenger market and Brazil, and the results found were very prominent. In terms of methodology, these two models have enabled different types of applications, using similar data source, achieving optimal solutions for a great set of nodes in a well-known complex problem.

The main contributions attained by the major/mini/direct model can be divided into three sub-classifications: the modeling, with the brand new features, especially those that allowed direct linkages through a known threshold and those regarding to the service radius distance for the mini hubs; and the application, which congregated a big set of Brazilian nodes with other 9 airports, represented by the most important airports in each one of other 9 countries in South America; and the methodology to obtain the W_{ij} data for the 50 x 50 matrix.

One of the advantages of the allowance of direct linkages is the avoidance of unnecessary transit flows through the hubs. As long as a flow between an i,j pair is greater than or equal to a known threshold. This is the case, for instance, for the passenger flows between the cities of Rio de Janeiro and São Paulo. It would not make any sense to connect or bundle these flows. Regarding the scope of major and mini hubs operations, the main contribution about the use of mini

hubs is the possibility of bundling and concentrating regional flows through the mini hubs. This fact avoids that intra-regional flows go to a major hub, with a consequent decrease in the flows going to the major hubs. Regarding the elaboration of the data, the use of two different data source and the application of a gravitational model also contributed for the new features presented in the methodology.

The two phase's model also made important contributions for the literature in the applied hub location models. The major contribution was the achievement of an optimal solution for a great set of nodes without making use of any heuristics. This was possible because the solution process was divided into two stages: the former one, by doing a generalization, due to some singularities based in the characteristics of the Brazilian air passenger market, in order to diminish the total number of nodes to integrate the final network. The latter used a hub location model to locate 3 hubs in Brazil, which also considered new features such as the allowance for direct linkages through a minimum threshold. In both Case Studies, the software TRANSCAD was used to visualize the pattern of the flows, which contributed to a better interpretation of the problems.

5.3 Suggestions for Future Studies

There still exists a vast area in the hub-and-spoke field to be explored, especially regarding real case applications, also for air transportation mode as well as for other modes of transportation. Nevertheless, the main advances might be concentrated in the development of more powerful solvers in the problems that aim exact solutions. In conceptual terms, what sounds very interesting is the simultaneous analysis of different networks with the objective to locate domestic hubs and international gateways.

Lots of challenges are noticed in this type of problems if real case applications are taken into consideration. Regarding the data, the difficulty stems from the possibility of acquiring contemporaneous flow data within the regions and between them. For instance, if the passenger air networks of Brazil and USA are considered together, only one well-known data (which is also used as a benchmark in the literature) is available, the CAB data, about passenger interactions amongst American cities in the year of 1978. Any Brazilian data of

this nature is not available. The interflow data between the two countries are also not available.

If the network cited above is considered, the problem modeling would consist of locating domestic hubs in each region in parallel to locating international gateways for each region. The domestic hubs, as the name suggests, would concentrate just the flows inside that region and the linkages between these hubs would have a discount factor. The international gateways would bundle all the international flows within a region from/to another region. In terms of the assignment issues for the spoke nodes to the domestic hubs and the international gateways, this could follow the rule set for single and multiple assignment allocation problems.