International Journal of
Science and Engineering Investigations vol. 4, issue 42, July 2015
ISSN: 2251-8843

Analysis of Flight Trajectories in a Terminal Maneuvering Area: São Paulo-Rio de Janeiro Route as a Case Study

João Luiz de Castro Fortes[1], Daniel Alberto Pamplona[2], Carlos Müller[3]
[1,2,3] Group of Air Traffic Engineering-GETA, Department of Civil Engineering, Aeronautics Institute of Technology-ITA, Brazil
([1]jlfortes@gmail.com, [2]pamplonadefesa@hotmail.com, [3]muller@ita.br)

Abstract- This study analyzes different operational characteristics from airline companies and through their flight trajectories in a Terminal Maneuvering Area (TMA). The work focus on flights operating in one of the busiest air routes in the world, São Paulo – Rio de Janeiro air route, as a case study. The study analyzes an 11-full-day radar database that allows the reconstruction of the real flight trajectories of all flights of the three main commercial airlines operating this route. The paper estimates each airline's average flight time performing standard arrival procedures (STAR charts) and standard instrument departure procedures (SID charts) and then, calculates different statistics in order to identify operational characteristics of each of one them. In addition, flight trajectories allowed some understanding about operational procedures adopted by air navigation service providers for flight sequencing at TMA.

Keywords- *Air Traffic, Trajectory Visualization, Terminal Manoeuvering Area*

I. INTRODUCTION

Air transportation has grown steadily along the last 20 years worldwide. According to [4], passenger-aircraft fleet will more than double in the next 20 years in the world. In certain regions, such as emerging countries, growth will be even higher than average, mainly due to economic growth. However, a major concern of all stakeholders related to this fact is avoiding that this significant growth may yield negative results in the system's operation such as delays and cancellations. With respect to this point, different approaches are being carried out in order to guarantee a healthy growth in aircraft operations. In the United States, Federal Aviation Administration (FAA) are implementing NextGen program. In Europe, EUROCONTROL is carrying the SESAR program. Among the emerging countries, it is possible to highlight the Brazilian program SIRIUS created by DECEA, country's airspace authority.

Although the programs mentioned before are being developed separately for each region it belongs to, their core objectives rely on the improvements of current operations through introducing new technologies or new concepts, such as Performance Based Navigations (PBN). Nonetheless, understanding of operational characteristics of both airlines and air traffic providers are essential inputs in order to planning improvement actions.

This paper analyzes the flight trajectories performed by the three main airlines operating at São Paulo/Congonhas Airport using a radar database corresponding to an 11-full-day period from 2010. The analysis allowed the extraction of important information on real flight operations such as statistics of travel time for each airline and the visualization of their trajectories, as well. It allows a great understanding of the procedures adopted by the air traffic control at TMA–SP in order to coordinate the flight sequencing at SBSP.

II. SÃO PAULO TERMINAL MANEUVERING AREA

In a continental-size country like Brazil, aviation has an important role in developing regional integration. Despite the various available connections between Brazilian cities offered by commercial airlines, the routes connecting the two largest cities in the country, Rio de Janeiro and São Paulo, through their domestic airports, Santos Dumont Airport (SBRJ) and Congonhas Airport (SBSP), it can be highlighted as densest one in the country. These routes have not only an important economic role for both the country and the airlines due to their high density, but they also have a major impact on air traffic for each city's Terminal Maneuvering Area (TMA), especially for TMA - SP due to the large number of movements it concentrates daily.

São Paulo Terminal Maneuvering Area (TMA-SP) is the busiest TMA in Brazil. According to [7], TMA-SP had in 2012 717,360 movements (about 22% of the total movements in all Brazilian terminal maneuvering areas). TMA-SP has inside its borders three main Brazilian airports: São Paulo International Airport/Guarulhos (SBGR), Campinas International Airport (SBKP), São Paulo/Congonhas Airport (SBSP) According to [12], TMA-SP covers an area of approximately 10,000 km2. For its vertical limits, it begins on the ground (GND) or on Mean Sea Level (MSL) and reaches up to the Flight Level 195 (FL 195), (about 6,000 meters).

As mentioned before, the traffic in this area has an intense density and coordinating the traffic in order to prevent congestions is the main task of air traffic controllers. Reference [8] identifies the congesting situation inside TMA-SP and develops a decision tool to help air traffic controllers in the flight sequencing for SBGR. Among all the routes that originate from TMA-SP, São Paulo-Rio de Janeiro is one of the busiest.

III. THE SÃO PAULO – RIO DE JANEIRO AIR ROUTE HISTORY

The air route between Rio de Janeiro and São Paulo, was known for a long time as the São Paulo – Rio de Janeiro "air bridge" ("ponte aérea" Rio de Janeiro – São Paulo, in portuguese). Service began in 1959 as an operating agreement between the major Brazilian airlines at that time (VARIG, VASP and Cruzeiro do Sul).

The companies used to offered several daily frequencies between SBSP and SBRJ at that time but many of them with departure time close to one another. The "air bridge" main idea was to distribute the frequencies evenly among the three companies in order to diminish the schedules overlap or gaps. In addition, this action allowed companies to operate under a higher load factor; for users, it allowed a greater availability of flights [5].

TABLE I. 2012 BUSIEST ROUTES AROUND THE WORLD [3]

Region	Route	Passengers 2012 (Thousands)	Growth 2012-2011	2012 Rank (change in ranking from 2011)
Asia	Jeju-Seoul	10,156	2%	1 (=)
Asia	Sapporo-Tokyo	8,211	8%	2 (+2)
Latin America	Rio de Janeiro-São Paulo	7,716	-1%	3 (-1)
Asia	Beijing-Shanghai	7,246	7%	4 (+3)
South West Pacific	Melbourne-Sydney	6,943	-2%	5 (=)
Asia	Osaka-Tokyo	6,744	-11%	6 (-3)
Asia	Fukuoka-Tokyo	6,640	-3%	7 (-1)
Asia	Hong Kong- Taipei	5,513	2%	8 (=)
Asia	Okinawa-Tokyo	4,584	12%	9 (new)
Africa	Cape Town-Johannesburg	4,407	-1%	10 (-1)

VARIG's CEO, Ruben Berta, suggested the term "Air Bridge" at that time inspired by the same term created by the Americans to refer to airborne operations in West Berlin, which was surrounded by the Soviet in postwar period [11].

The air route between these two cities has grown rapidly since then, reaching in 2012 the rank as the third busiest in the world (the busiest in Latin America) with annual turnover of 7.76 million passengers, as seen in Fig. 1, according reference [3]. According to [9], the number of annual passengers in this route has more than doubled in the last 20 years.

Nowadays, the original concept of the Rio de Janeiro – São Paulo "air bridge" is not in place anymore and the route is operated with no cooperation among airlines as it was in the past; nevertheless the amount of operations in TMA-SP is still quite expressive. According to [2], timetable for commercial flights in January 2014, there were 11,589 regular flights operating weekly at the TMA-SP's four airports. Out of those flights, 935 flights were operating the route SBSP-SBRJ-SBSP, corresponding to approximately 8 % of all TMA-SP's regular operations.

IV. METHODOLOGY

The 11-full-day radar database for TMA-SP used in this paper is composed of information acquired from 7 radars located in the TMA-SP, shown in fig. 2. The radars capture at each antenna revolution (approximately every 4 seconds) information from each aircraft flying through the airspace that is inside its coverage (commercial flights, general aviation and even helicopters). Aircraft's position (latitude and longitude), speed, flight level, transponder code SSR3, flight trend, heading and radar's signal quality are among the information that is captured.

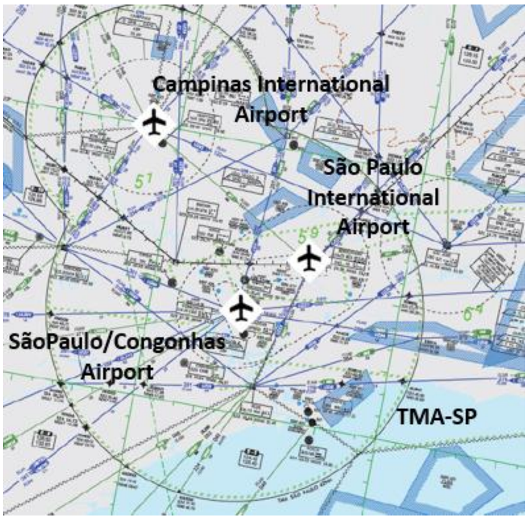

Figure 1. TMA-SP configuration at 2010 and its main airports' location.

The area with recorded radar information is a square centered at SBSP (coordinates 26.62533° S and 46.6533° W) with sides of 256 NM in length. Due to the huge amount of information gathered during a day (most text files are bigger than 1 gigabyte) the generated tapes are not easily tractable with normal spreadsheet editors, such as Excel. Therefore, a Structured Query Language (SQL) database management system was required to deal with this huge amount of the data. POSTGRESQL 8.4, an open-source database management system developed at the University of Berkeley in 1986 [13], was selected for that purpose. It allows filtering data of interest through a more efficient and quicker way.

The analysis also required the ability of plotting data into maps to allow the visualization of flight trajectories and their patterns so to compare with the standard procedures (STAR and SID) at the TMA-SP.

Fig. 2 shows the information gathered in a tape for a full day of operations, excluding the traffic of helicopters (that in general uses "00" in the transponder's code final digits), limited to a 40-NM square around SBSP. Each dot in the figure represents the position of an aircraft at a certain time of the day. The figure allows the visualization of the patterns of departures and arrivals at SBSP and of the intersection points in the procedures that concentrates over certain navigation aids.

At the end, the analysis evaluates flight travel time and travel distance in the standard arrival procedures (STAR) and standard instrument departures procedures (SID) at SBSP. RAMS Plus was used to replicate the flights radar data in order to obtain travel time and travel distance along the procedures and from one navigation aid to another.

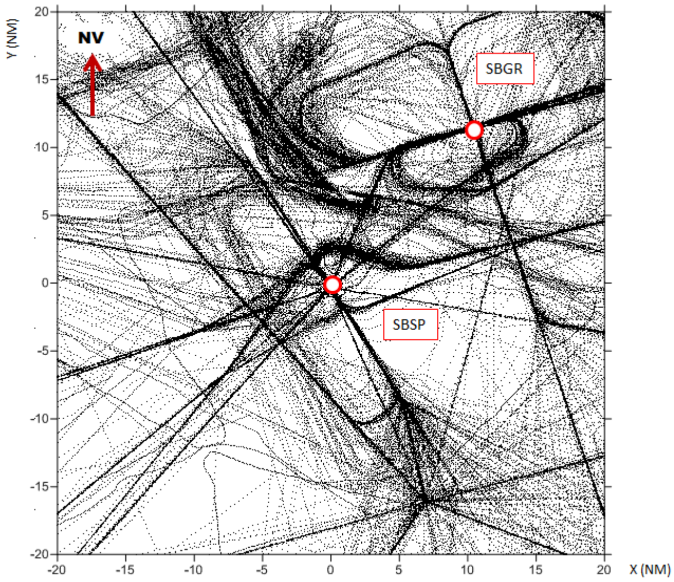

Figure 2. A full day operations around SBSP. (NV: True North)

V. DATA ANALYSIS

The travel time of each aircraft during a SID or STAR procedure at SBSP was determined for each runway's threshold and a specific exit (SID) or entry (STAR) waypoint (geographically defined by its latitude and longitude) in the procedure.

The study focused on the flights of the airlines that operate Rio de Janeiro – São Paulo air route and use category C aircraft according to International Civil Aviation Organization (ICAO)'s Annex 14 [10]. Flight trajectories from three airlines (here named AAA, BBB and CCC) which operate in this air route were studied.

The period of study comprehended tapes 1 to 11, accounting for 11 full-day flight records. Each full-day for SBSP includes flight data from 06:00 up to 23:00 local time due to the airport regular operational period, restricted by the need to comply with a noise reduction determination.

Schematic representations of the SID and STAR procedures for SBSP are shown in fig. 3 and 4. The dashed lines represent the standard paths to be followed by an aircraft during departures or arrivals, depending on the runway threshold being used. SBSP has a runway with thresholds 17R and 35L. The threshold most used, according to airport's operator, is threshold 17R. As shown in these figures, the entry and exit waypoints for these procedures at TMA-SP are, respectively, SULCO and LOPES (represented by triangles), although the published procedures go up to LITRE or COSME, as shown.

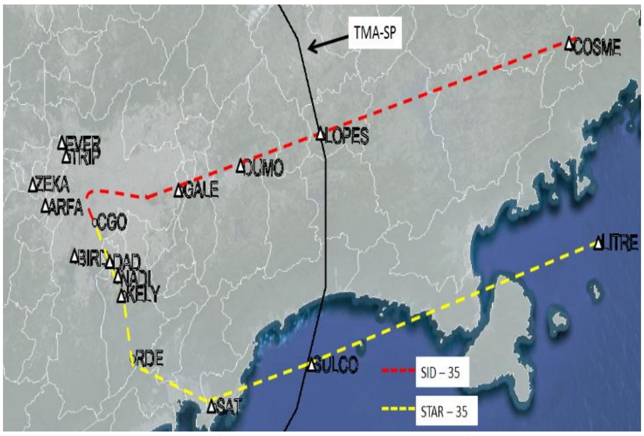

Figure 3. Scheme of SID and STAR procedures for threshold 35L.

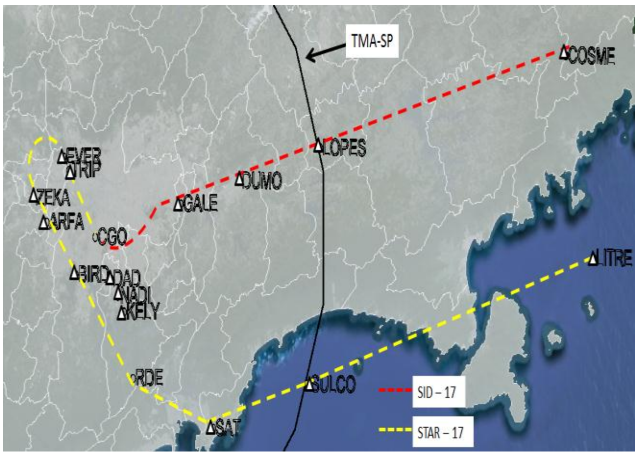

Figure 4. Scheme of SID and STAR procedures for threshold 17R.

Google Earth developed by Google was used before any calculation of travel time or distance in order to visualize flight trajectories recovered from the radar database, as well as the SID's and STAR's waypoints (as can be seen in Figure 5).

Google Earth presents a tridimensional model of the Earth and it allows plotting georeferenced positions in its surface. Hence, making the TMA-SP visualization possible.

The visualization showed that not all flights trajectories could be recovered all the way to the last waypoint, COSME, at a SID procedure or from the first waypoint, LITRE, in a STAR procedure. Not all flights have their full path captured by the radars. Therefore, in order to capture most of the available flights and to keep flights flying over the same number of waypoints flights were tracked up to waypoint LOPES (in a SID procedure) and from waypoint SULCO (in a STAR procedure).

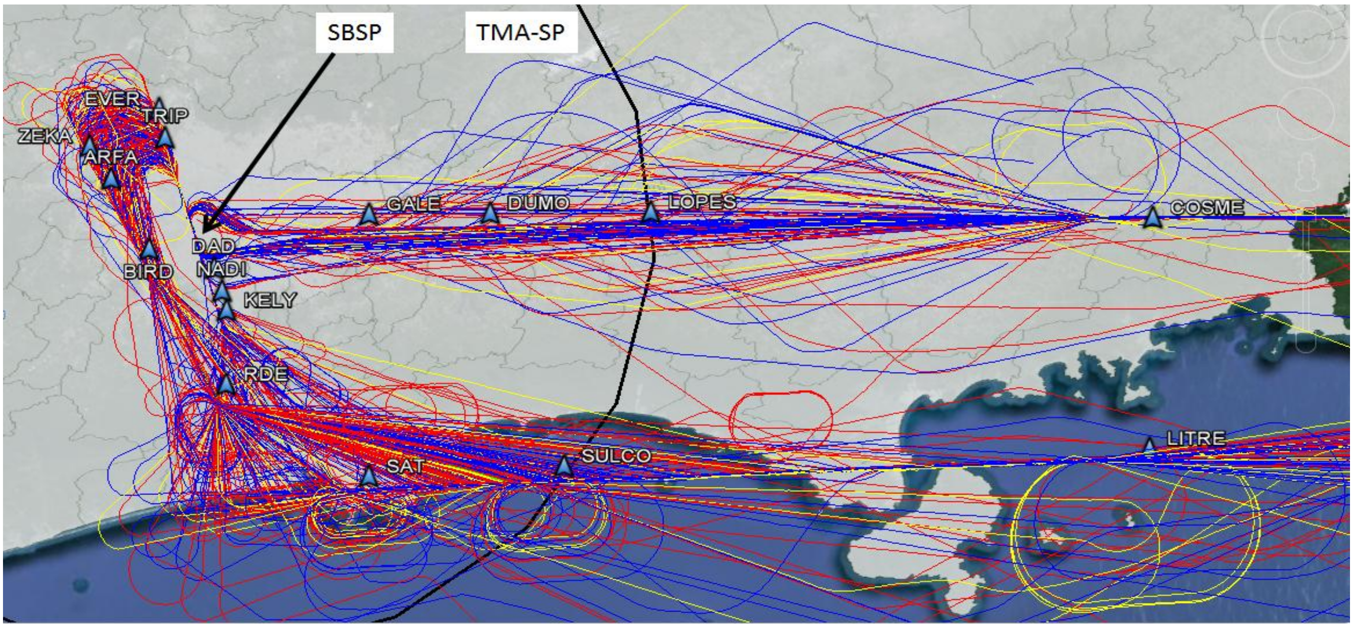

Figure 5. Overview of the studied trajectories.

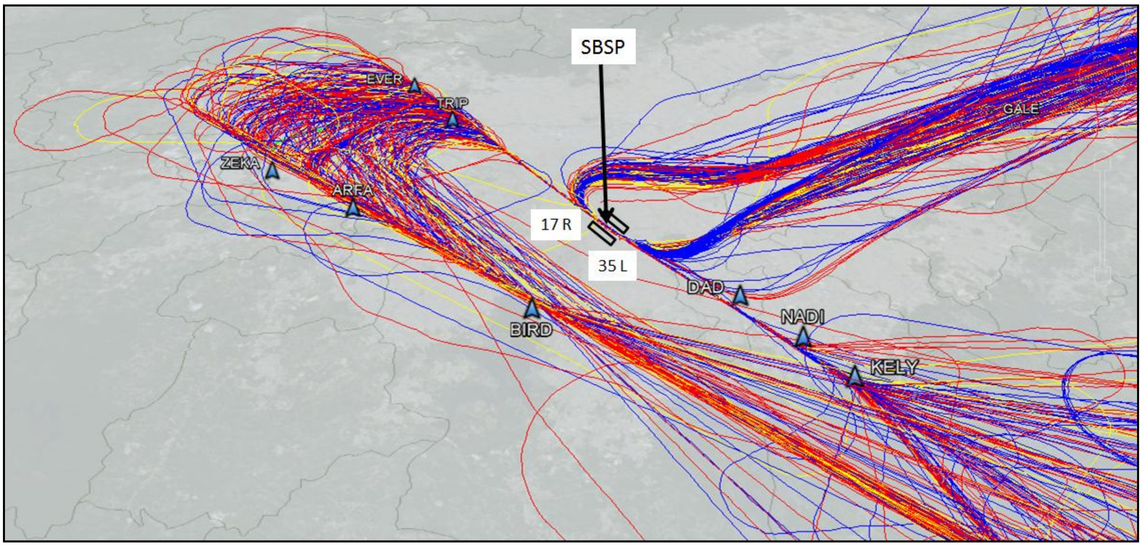

Figure 6. Flight trajectories closer to SBSP

Flight trajectories shown in Figure 5 account for all flights in the radar database for the 11 full-day period of study. Each color represents an airline that, for this work, had their name changed to AAA (blue), BBB (red) and CCC (yellow). It is possible to visualize that departures follow SID procedures closely most of the time, with few deviations observed. Deviations along the departure path were mainly caused by severe meteorological conditions.

Nonetheless, arrival procedures presented a larger dispersion after SULCO. The number of trajectory vectoring issued by traffic controllers is very large and the presence of holding patterns (mainly over SULCO, SAT and RDE) may represent traffic congestion at that time. This could be explained by the fact that other flights going to others airports such as SBKP use that path as well. Therefore, the necessity of sequencing flights and keeping separation between aircraft may cause the deviations and holding patterns.

It is possible to observe a large number of aircraft flying from SAT to RDE through a path much longer than the one published in the SID procedure. This evidences that, in order to accommodate all arriving and departing flights at the airport, a huge number of vectoring maneuvers have to be made. In addition, this implicates in an increased workload for the air traffic controller in order to do the guiding through the TMA-SP to the airport.

Figure 6 gives a closer view of arrival and departure flights zooming in at SBSP. The arrival procedure shows also some dispersion in its final segment. It is possible to observe that some flights travel a great distance before finally aligning up to runway 17R. These stretched paths work similarly to the holding patterns seen before. Air traffic controllers sometimes create stretched paths in order to adjust the flight sequencing in order to accommodate departures between arrivals. This procedure is called “trombone”, due to its shape. On the other hand, arrival flight paths using runway 35L have a much smaller dispersion. This explains the fact that eventual arrival holding procedures and path stretching are applied before the flights crosses waypoint RDE.

Table 1 shows travel times for the three airlines in TMA-SP. Initially, it is interesting to point out that, as expected, around 70% of the time, threshold 17R was the main one. It is also important to realize that 17R’s standard arrival procedure is almost 17% longer than that for runway 35L.

Regarding the average flight travel times at TMA-SP for each airline, it is possible to see that the average flight travel times for airline AAA are longer than other airlines’ (BBB and CCC) in both departure and arrival procedures.

A hypothesis test was performed in order to compare each group of two airline’s average time. In other words, the main idea is to identify if these average time are statistically different or not. The two-tail t-test was .used considering different variances, assuming independency between the sample and a 95% confidence level.

The t-stat, t-critical values for two-tail test for each comparison are presented in Table III. If t-stat is inside interval of critical value, then it is possible to consider that the difference between the two average times is zero. Otherwise, they are different. The probability of this difference being zero – $P(T \leq t)$ – is also presented in the same table.

Regarding arrivals using threshold 17R, it is possible to see that the average time for all three airlines are statistically different. Considering threshold 35L, it is possible for consider that average time for AAA and CCC is the same.

Regarding departures, the results for thresholds 17R and 35L show that the average time for all airlines can be considered statistically the same.

These test results may be justified to the great dispersion presented during arrivals. Therefore,

TABLE II. EXTRACTED INFORMATION FROM TRAJECTORIES DATA

Threshold	Operation	Airlines	Total Sample	Average Time (s)	Minimum Value (s)	Maximum Value (s)	Standard Deviation (s)	THR Usage
17R	Departure	AAA	172	512.63	438.00	962.00	43.19	76.4%
		BBB	63	500.75	407.00	564.00	31.40	82.9%
		CCC	157	499.20	416.00	577.00	22.49	75.1%
	Arrival	AAA	163	1297.66	752.00	2924.00	282.47	75.1%
		BBB	55	1268.91	724.00	2128.00	312.19	84.6%
		CCC	156	1268.76	888.00	2587.00	230.17	75.4%
35L	Departure	AAA	53	533.81	456.00	668.00	34.64	24.4%
		BBB	13	518.15	468.00	547.00	25.59	17.1%
		CCC	52	534.58	482.00	626.00	27.35	24.9%
	Arrival	AAA	54	990.87	656.00	3080.00	389.21	24.9%
		BBB	10	1022.20	680.00	1696.00	384.11	15.4%
		CCC	51	1006.55	692.00	2960.00	372.14	24.6%

TABLE III. EVALUATION OF TRAJECTORIES DISPERSION

Threshold	Path	Average Comparison (Airlines)	t-Stat	t Critical two-tail	P(T ≤ t)
17R	LITRE-CGO	AAA e BBB	5.1882050492	1.9782385392	0.0000007872
		AAA e CCC	3.5819455687	1.9690597153	0.0004064544
		BBB e CCC	3.0499637786	1.9921021540	0.0031623248
	CGO-LOPES	AAA e BBB	0.6046294246	1.9879342062	0.5470172035
		AAA e CCC	1.0039013705	1.9676708854	0.3162116438
		BBB e CCC	-0.0033225720	1.9916726096	0.9973576819
35L	LITRE-CGO	AAA e BBB	1.8322651919	2.0638985616	0.0793500319
		AAA e CCC	-0.1258231659	1.9842169516	0.9001270727
		BBB e CCC	2.0407202805	2.0930240544	0.0554212177
	CGO-LOPES	AAA e BBB	-0.2364301885	2.1603686565	0.8167833282
		AAA e CCC	-0.2110162391	1.9832641448	0.8332915255
		BBB e CCC	-0.1184139181	2.1603686565	0.9075498502

VI. CONCLUSIONS

Around the world, countries are developing different programs focusing on improving airspace use through the introduction of new concepts and processes. However, an analysis of current conditions and operations is essential for moving forward.

This study presented an analysis of one of the densest routes in the world, the air route connecting São Paulo/Congonhas Airport and Rio de Janeiro/Santos Dumont Airport. The work focused on the analysis of trajectories and travel times for an 11-day period. It was shown that during arrivals, air traffic congestion might result in longer distances travelled by airlines due to the number of vectoring maneuvers done by air traffic controller. This may be observed through the trajectories images that presented a great dispersion if compared to the standard procedure. In the other hand, as for the arrivals procedures, the travel times performed by the three companies are statically the same. These results indicate that there are certain nuances in the procedures that must be adequately considered in the capacity studies and in the proposal for improvements in airspace, especially in TMA-SP's aircraft flow. It is possible to clearly identify the necessity for air traffic controllers to determine spacing between aircraft in order to accommodate arrivals and departures and to control air traffic saturations which may be caused by the excessive number of flights operating in the area.

REFERENCES

[1] AIRBUS, "Global Market Forecast. Future Journeys 2013 – 2032", 2013.

[2] Agência Nacional de Aviação Civil – ANAC. "Airlines timetable (HOTRAN)". Available at www.anac.gov.br. Last access in September 2nd-, 2012.

[3] Amadeus Air Traffic Intelligence, "Busiest air routes in 2012"; Available at www.amadeus.com.

[4] BOEING, "Current market outlook 2013 – 2032", 2013

[5] G. Beting. "Matéria Ponte Aérea". Flap Internacional Magazine. pp. 2-20. March 8th 2007.

[6] DECEA (2012). Available at http://www.decea.gov.br/espaco-aereo/gerenciamento-de-trafego-aereo. Last access June 30th 2012.

[7] DECEA (2013). "Anuário estatístico de tráfego aéreo 2012".

[8] D. Dias, C. Müller, P. Porto, P., "Aircraft spacing for continuous descent approach in a terminal area based on required time fo arrival at a metering fix", Journal of the Brazilian Air Transportation Research Society, vol. 7, Issue 2, 2011, pp. 25-34.

[9] IBGE (2010). "Ligaçoes e fluxos do território. ligações aéreas 2010".

[10] International Civil AviationOrganisation – ICAO. Annex 14 to the Convention on Civil Aviation. Volume I: Aerodrome and Desing Operations, 6th edition, 2013.

[11] JETSITE, "Ponte aérea: uma grande idéia brasileira"; Available at www.jetsite.com, 2012.

[12] J. L. Outeiro, "Increase of airspace capacity through new sectors – study case of São Paulo terminal area", Journal of the Brazilian Air Transportation Research Society, vol. 8, Issue 1, 2012, pp. 55-72.

[13] PostgreSQLBR, "PostgreSQL Manual", Available at http://www.postgresql.org.br/, last access in August 8th, 2012.