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An Analysis of Flexible Air Routes between the São Paulo and Rio de Janeiro Terminal Maneuvering Areas

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Abstract- The objective of this paper is to compare two airspace configurations, the first being the current rigid structure and, the second, the dynamically reconfiguring structure. The later differs from current configuration by implementing runway usage modifications on demand. In such comparative analysis, simulation tools are commonly used to develop and validate new layout and concepts on Air Traffic Management (ATM) procedures, with the goal of supporting the decision making process. Air Traffic Dynamic Management (ADM) has been heavily utilized to expand airspace limitations and to reduce delays under demand increase at Terminal Maneuvering Areas (TMAs). This paper aims to analyze the route time, fuel consumption and CO_2 emissions between São Paulo and Rio de Janeiro airports, through fast-time simulation using the TAAM package. The results indicate that a flexible airspace configuration, changing the direction of the airway, could result in a reduction of 2,18 % in fuel consumption, which represents, at the current exchange rates and fuel prices, a yearly reduction in operational costs of USD 1,68 million. Other operational costs, such as crew and maintenance for instance, could be reduced in USD 1,0 million.

Keywords- *Air Traffic Management, Flexible Airspace, Dyanamic Configuration*

I. Introduction

The unprecedented air transportation growth experienced in Brazil in the last decade has culminated in an increase in congestions and delays. According to [1], this steep increase will continue, and the forecasted growth rate between 2013 and 2032 is of 5,0% annually. Additionally, studies [2] suggest that the global number of passengers will increase from 3,1 billion in 2013 to 6,4 billion in 2030, which can potentially result in increasing delays and, as a consequence, higher operational costs to airlines. Hence, this scenario presents not only a challenge to the Brazilian air transport, instead, it can be addressed globally. In response to that, Air Traffic Management (ATM) programs aiming to improve the efficiency of airline operations, by reducing congestions and increasing operational efficiency, have been launched worldwide. Furthermore, these programs also aim to reduce flight path and *en route* time, decreasing fuel consumption and carbon dioxide emissions. Examples of such programs include the NextGen, created by the Federal Aviation Administration (FAA) in the United States and the SESAR, from EUROCONTROL, in Europe.

In order to meet national needs and ensure the development of the Brazilian air transport, following the International Civil Aviation Organization's (ICAO) planning, the Airspace Control Department (DECEA) developed the SIRIUS Program, aiming to implement the ATM concept of operation in Brazil. The implementation of the PBN (Performance Based Navigation) operation aims to incorporate a number of benefits, such as increasing the safety and the efficient use of the airspace, as well as the implementation of the Area Navigation (RNAV) procedure and Required Navigation Performance (RNP).

Since 2011, the PBN started to be implemented at the TMAs of Recife, Brasilia, Rio de Janeiro, São Paulo and Belo Horizonte. In the light of the above, this paper aims to analyze the changes on route time, fuel consumption and CO_2 emissions under the dynamic reconfiguration of the airway between the TMAs of São Paulo and Rio de Janeiro. This route has been chosen for the case study because it is considered to be one of the most import and busiest Brazilian air routes [3].

II. Literature Review

Airspace structures are designed to guarantee safe and efficient operations. It is a consensus in the academia that in order to accommodate the increasing traffic, it is necessary to develop new systems that raise airspace capacity, which has been exceeded by the demand [4]. Despite the navigation aids and new technological advances in communication and data link systems, the air transportation system still has, in several aspects, rigid structures, such as in sectors, waypoints and airways.

In order to accommodate the increasing demand in an efficient manner, these currently rigid structures need to be transformed. This may be achieved by introducing a more flexible arrangement, with dynamically allocated routes that are sensitive to weather and workload variations [5]. According to [6], the dynamic rearrangement of routes and sectors can lead to a reduction in operational delays and costs. In this context, the Dynamic Airspace Configuration (DAC) proposes the transformation of the static airspaces into dynamic ones, optimizing airspace usage and consequently increasing its capacity.

The airspace configuration should be designed according to a daily basis demand, relying on the actual operational requirements. Five different methods to transform a rigid structure into a flexible one are presented in [7].

Simulation tools have been widely employed in different engineering fields. Among the many possible applications of simulation in air transportation studies, a recent trend has been seen in studies concerning the impact of infrastructure modifications, especially for capacity and delay estimation, sectorization projects (Standard Instrument Departure and Standard Terminal Arrival Routes) in maneuvering areas and aircraft performance In order to render useful and reliable information, simulation software rely on accurate databases, such as the Aircraft Performance Model (APM) of the BADA (Base of Aircraft Data), developed and maintained by EUROCONTROL in cooperation with aircraft manufactures, which is capable of accurately predicting aircraft trajectories and calculate its performance parameters.

Due to the inherently long events that comprise air transport operations, fast-time simulation has become an important tool to reduce simulation time and costs. Furthermore, modern simulation packages contemplate built-in conflict resolution tools, enhancing their capability of representing complex real systems. For that reason, the present study was developed using the TAAM (Total Airspace and Airport Modeler) one the most widely used simulation packages, based on 4D trajectories (three spatial dimensions plus time), capable of predicting delays based on trajectory distortions. Additionally, TAAM makes use of the APM database for aircraft performance simulation.

III. PROBLEM DESCRIPTION AND MODEL DEVELOPEMNT

The TMA is perhaps the most complex type of airspace [8], where the most demanded airports are located. The São Paulo and Rio de Janeiro TMAs have the first and second, respectively, largest number of movements in the Brazilian airspace. Guarulhos International Airport (ICAO: SBGR; IATA: GRU) is the most important Brazilian airport, with more than 38 million passengers transported in 2015 and 300.000 aircraft movements [9]. Congonhas Airport (ICAO: SBSP; IATA: CGH), on the other hand, follows as the second most important airport in the São Paulo state, with close to 20 million passengers and 220.000 movements in 2015 [9]. It is important to point out that Guarulhos and Congonhas are both located at the State of São Paulo, the main business center in Brazil. Additionally, Viracopos Airport, located at the city of Campinas (120 km of the capital, São Paulo) has shown considerable growth after the government concession plan.

Furthermore, Rio de Janeiro International Airport (SBGL) and Santos Dumont Airport (SBRJ), located at the state of Rio de Janeiro, also have an expressive number of flights. Figure 1 shows the number of passengers transported in the last four years in each of these airports.

Due to the importance of the airports located in São Paulo, an airspace structure that aims to prioritize them could represent an economic improvement not only to the airlines that operate in these routes, but also to the passengers, reducing flight time and potentially travel costs. The current airspace between the airports of São Paulo and Rio de Janeiro, depicted in Figure 3, was designed in 2013, and consists of a tube structure with 5 parallel routes, one of them with restricted operation, due to its proximity to a Brazilian Air Force training center. More specifically, between 08:00 and 16:00h (Brasília Time - BRT), there are only four airways in operation. Therefore, in order to apply the dynamic air routes system, another configuration was created with 4 parallel routes.

Based on TATIC (Total Air Traffic Information Control) data obtained from the Air Navigation Management Center (CGNA), under the command of the Airspace Control Department of Brazil, information about the use of each of the five target airports was collected and processed. The necessary information about flight schedules, such as arrival and/or departure times, origin/destination airports and aircraft type, was obtained.

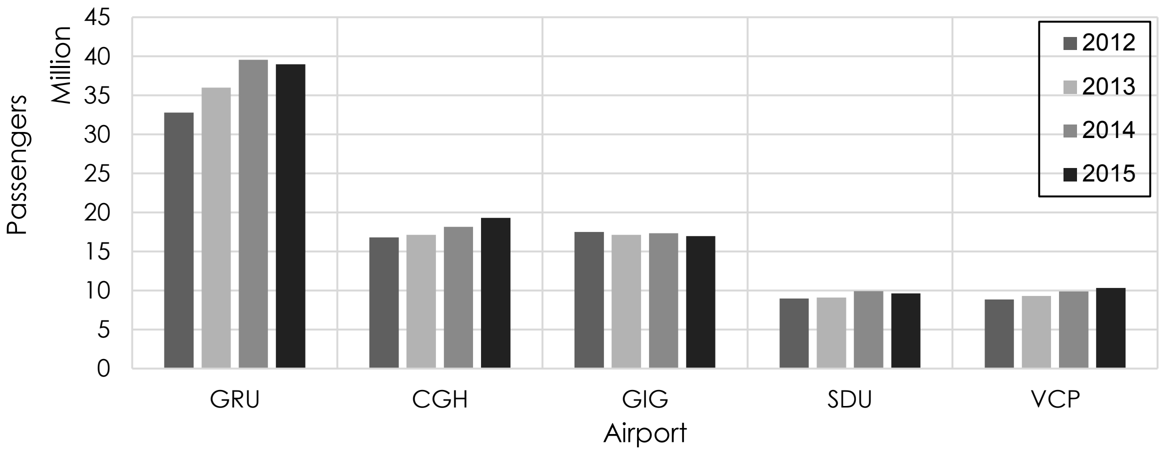

Figure 1. Number of passengers between 2012 and 2013 at the studied airports.

Additionally, Table 1 shows the number of movements between 2012 and 2015 in these five airports. It is important to point out that in the 2015, as a consequence of the Brazilian economic crises, the air traffic demand decreased in almost all airports.

TABLE I. NUMBER OF MOVEMENTS BETWEEN 2012 AND 2015 AT THE STUDIED AIRPORTS

Year	2012	2013	2014	2015
Guarulhos	279.036	290.436	310.690	299.457
Congonhas	227.240	222.902	216.133	221.534
Galeão	166.076	155.126	151.282	141.529
Santos Dumont	169.744	157.117	150.575	139.561
Viracopos	118.808	131.240	135.319	131.537

In order to analyze the probability of each combination of simultaneous runway use, a one-year dataset was analyzed (between July 2014 and August 2015). Its probability was studied due to the proximity of these five airports and to verify if the climate conditions would impact in two different airports. The data showed that 16 (The total possible combinations (32) is equal to the square of the number of runways (5)) combinations are responsible for 94.10% of the operations.

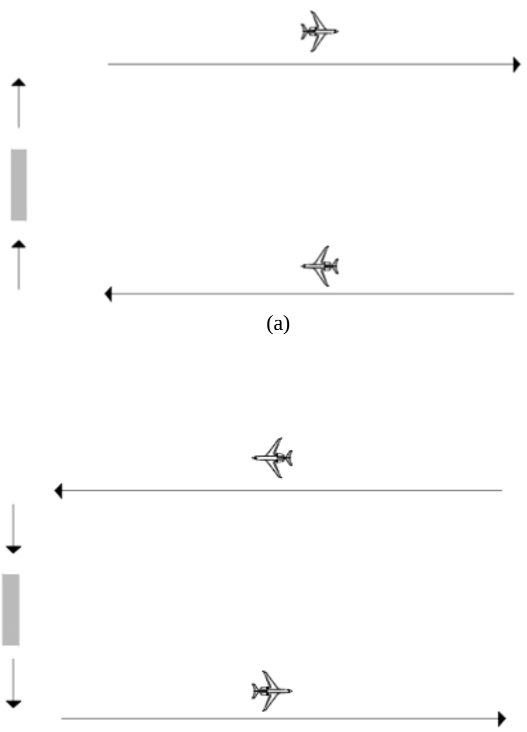

Figure 2. Flexible airway - different directions. (a) Current Configuration (b) Alternative Configuration

IV. ASSUMPTIONS

During the process of developing procedures for approach and departure, it was assumed that aircrafts and pilots are certified to operate with the RNP aid (which is already a reality in Brazil, according to professionals). Additionally, switching between airways must be done with the air traffic controller's support (which also happens today during procedure modifications in runway use) and the levels of flight used are the same adopted by the Reduced Vertical Separation Minimum (RVSM), in order to avoid collisions during airway alternation.

V. SIMULATION AND MODEL VALIDATION

The primary input settings used in the simulation were: the flight schedule and pathway (waypoints), the current layout of TMAs of São Paulo and Rio de Janeiro, the infrastructure and layout of these five airports (as well as the others involved in the schedule). Moreover, the flight level and cruising speed, sectors and their configurations were added. The database of the APM, built into TAAM was used.

Furthermore, according to the Transportation Schedule (HOTRAN) from the Brazilian National Agency of Civil Aviation (ANAC), there are more than 1.860 weekly flights between the TMAs of São Paulo and Rio de Janeiro, from which 48% are between Congonhas and Santos Dumont Airports. In addition, the TATIC base revealed that, in a regular day, approximately 2.080 flights between the aforementioned TMAs have as their origin or destination one of the five airports analyzed in this study. Baring this in mind, the dataset used in the simulation was obtained from a statistically representative day within the studied time frame that represents a regular/average day in the air traffic between these TMAs. It is important to point out that HOTRAN only estimates the number of slots allocated to each carrier. On the other hand, the TATIC shows the actual data, based on recorded events.

To ensure a safe and orderly air traffic flow, all the air traffic rules published by DECEA were used in the simulation. The longitudinal, vertical and lateral separation rules were used according to ICA 100-37 and ICA 100-12. These rules were fed in the simulator in order to guarantee boundary conditions for the conflict resolution tool. The RVSM procedure currently in use at the Rio de Janeiro and São Paulo airspaces, that aims to increase its capacity, was also considered. The cruising levels are separated into odd and even, according to the flight's direction. It is noteworthy that the scenario developed in this study will use these levels in order to promote change on the airway after the alteration in the runway usage.

In order to validate the model implementation and the air traffic rules, a number of simulations using the real air traffic demand data provided by CGNA were executed in cooperation with the Brazilian Institute of Airspace Control (ICEA). Firstly, a base scenario, contemplating the current rigid air structure, was developed to provide an accurate threshold for a comparative analysis between simulated and real dataset values.

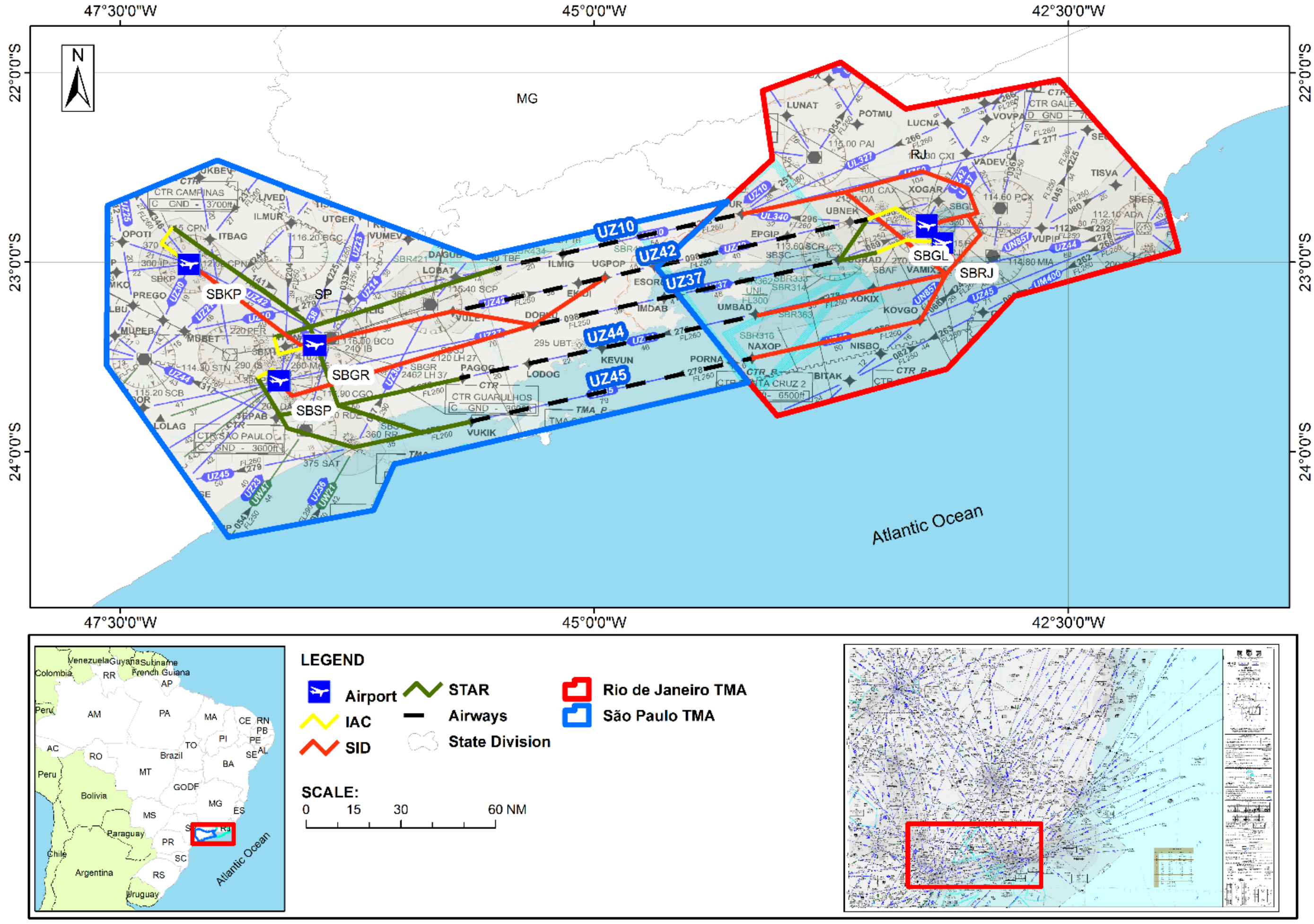

Figure 3. Current airspace structure at São Paulo and Rio de Janeiro TMAs.

The statistical difference between the simulated scenario and real dataset was analyzed using a two-sample Z-test. The null hypothesis is that the mean flight time of both sets are statistically equal, and the alternative hypothesis, on the other hand, that they are statistically different. The test was conducted at a pre-specified significance level of $\alpha < 0.05$. To assure comparable performance results, each aircraft used in each route was considered a different treatment and the dataset was blocked (divided in groups). The four different aircraft models used in twelve possible routes resulted in 28 different comparisons, and all of them showed that the null hypothesis could not be rejected. In other words, the results obtained in the simulation are statistically identical to the real dataset. Since the real fuel consumption data is not available (the companies do not provide this information), the total time spent by the aircraft, from departure until arrival, was used as the efficiency parameter. Figure 4 shows the comparison between the simulated and real *en route* times for the A320 aircraft model.

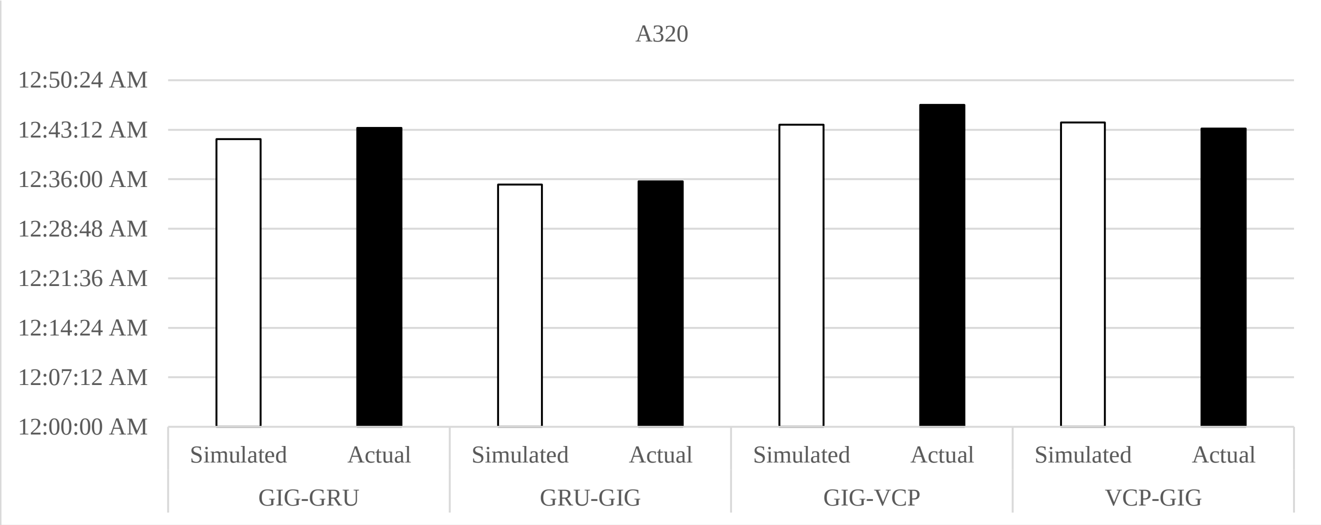

Figure 4. Comparison between the simulated and actual en route time

After validating the base scenario, an alternative scenario was developed, consisting of a dynamic tube structure with 4 parallel routes, as shown in Figure 5. According to [9], the use of dynamic tubes can reduce the workload of the controllers, and, the fuel consumption could also be reduced as a result of shorter routes [12].

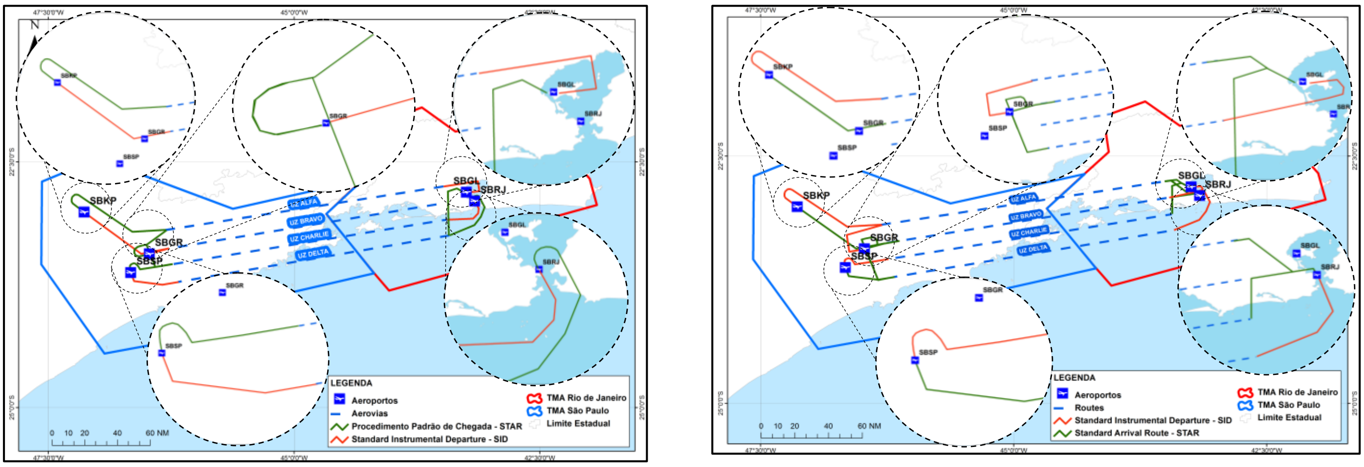

Figure 5. Flexible airspace designed

VI. Results and Discussions

The following section presents the results from the comparative studies, conducted between base and alternative scenarios.

A. Fuel Consumption

The main objective of this paper was to determine if the flexible airspace structure could provide a reduction in fuel consumption, and, as a result, operational costs. Table 2 shows the results for both the current (baseline) and the proposed airspace structure.

As the change in direction of the airways reaches all parts of the airspace (SID, STAR and airway), some of the routes have undergone stretching, increasing, therefore, fuel consumption. On the other hand, most of the airways were reduced, resulting in lower fuel consumption.

TABLE II. FUEL CONSUMPTION ON THE BASELINE AND ALTERNATIVE SCENARIOS

Route	Baseline Scenario (kg)	Alternative Scenario (kg)
GIG-GRU	2.022,79	1.854,31
GRU-GIG	1.617,75	1.568,48
GIG-VCP	2.029,70	1.981,92
VCP-GIG	1.980,13	1.945,03
GIG-CGH	1.986,83	1.845,90
CGH-GIG	1.665,21	1.716,90
GRU-SDU	1.573,36	1.599,74
SDU-GRU	1.945,36	1.789,40
VCP-SDU	1.889,92	1.886,84
SDU-VCP	1.880,45	2.048,48
SDU-CGH	1.901,86	1.775,46
CGH-SDU	1.664,99	1.680,34

The route GIG-GRU presented the largest reduction with 8.33%, followed by SDU-GRU with 8,02% and SDU-CGH with 6.65%. However, the route between SDU and VCP increased in 8.94%.

The proposed airspace structure results in reduced fuel consumption in 8 out of the 12 possible routes. According to simulation results, the total amount of fuel saved in one year would be approximately 3,744,577.72 kg, that represents a reduction of 2,18% in comparison to the current fuel consumption. At current exchange rates and the fuel price, such reduction corresponds to USD 1,688,458.23 (The jet fuel price used was extract from www.indexmundi.com from June, 2016)

The relatively short (about 180 NM) routes between São Paulo and Rio de Janeiro, associated with the steep topography of Rio de Janeiro, make the fuel consumption during take-off and landing represent almost 77% of the total consumption, with cruise flight representing only 15%.

B. Enroute Time

The dynamic airspace structure developed in this study presented a reduction of 552 flight hours when compared with the current one. According to data from Conklin & de Decker, there are costs related to maintenance, crew expenses, among others, that correspond, on average, to U$ 1.816,15 per flight hour (The hourly cost was obtained from www.conklindd.com). Based on this average cost, the proposed flexible airspace configuration could potentially reduce these operation related costs in U$ 1,002,514.80.

C. CO2 Emissions

The carbon dioxide emissions are directly proportional to the fuel consumption; hence, in the alternative scenario emissions were also reduced in 2.18%. According to ICAO, for 1 kg of Jet-A fuel, 3,157 kg of CO2 are produced. As a result, the total amount of CO_2 reduced by the flexible airspace structure would be 11,821 tons for one-year traffic.

VII. CONCLUSIONS

Programs around the world have been developed aiming to improve airspace capacity and efficiency through the introduction of new concepts, such as dynamic airspace structures.

A fast-time simulation was carried out in order to compare the current Brazilian rigid airspace structure and a new dynamic design operation between the TMAs of the states of São Paulo and Rio de Janeiro, which are among the densest airspaces in the world. The main investigated performance parameters were flight time, fuel consumption and CO2 emissions. The study was carried out using a real database with 2.080 flights that was compared with simulation results obtained with the TAAM software package. Simulation results for a total of twelve possible routes were validated through statistical comparative experiments.

The results indicate that the flexible airspace configuration could provide an efficient optimization in flights for the airlines, reducing fuel consumption, flight time and, consequently, their ecological footprint. According to simulation results, a reduction of 552 flight hours and 2,18% in fuel consumption was obtained, compared to simulation results of the current airspace structure.

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