POPULATION DENSITIES AND REAL ESTATE DEVELOPMENT ON THE ALIGNMENT OF SÃO PAULO'S CONGONHAS AND GUARULHOS AIRPORTS' RUNWAYS: THE REPLICATION OF A CONFLICTUAL FATE

Luiz Henrique Werneck de Oliveira
Ph.D., Territory Planning and Management, M.Sc. Civil-Hydraulic Engineering, B.Sc. Sanitary Engineering, B.Sc. Social Sciences
PGT-UFABC; Zukunft Consulting

*** Corresponding author e-mail address**: luizwerneck64@gmail.com

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ABSTRACT

Urban development surrounding commercial airports is a conflictual factor that hampers airport operations and ultimately prevents it to expand its infrastructure. São Paulo is a 12 million city with 22 million people on its metropolitan areas and is served by the more central Congonhas Airport (22 million passengers in 2019) and the larger, international Guarulhos airport (46 million passengers in 2019). Congonhas has been completely surrounded by urban development and the hypothesis of this study is to verify to what extent the same process is happening around Guarulhos. This study investigates data on population density on runway alignments as well as the trend of real estate development from 1985 to 2013 by using Geographical Information Systems' "heat maps". The 2010 population was computed in Census sectors within 10km radius from both airports. Real estate development of both aligned and dis-aligned radial rings from 0-2km, 2-4km, 4-6km, 6-8km and 8-10km radius were computed in several 5 (and 4) years' periods. Results show intense real estate development northwest of Congonhas from 1985 (the year of Guarulhos airport opening) to 2004, with a similar pattern the western alignment of Guarulhos airport' runways since 2005. High population densities are noted in 2010 also south of Congonhas and east of Guarulhos airports, where little or no real estate development was noted within the 1985-2013 period, thereby representing informal dwellings. Evidence shows that the same urban development conflicting with Congonhas Airport is being replicated in the vicinity of Guarulhos airport, already surrounded by urban development and unable to expand its runway systems, restricting capacity of São Paulo's airports system. These facts put further challenges both for airport and urban planners to increasing airport capacity at São Paulo.

Keywords: São Paulo (Brazil), Congonhas Airport, Guarulhos Airport, Urban Sprawl, Real Estate Development.

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1. INTRODUCTION

Civil aviation and urban sprawl increased their growth paces simultaneously over the past decades. Earlier airports were built in what once were the fringes of the cities they served. After World War II flying became more popular and civil aviation grew. Airports built in the 1920's and 1930 later needed longer runways. In some cases, airports' expansion was impossible due to urban development around them. The advent of jet aircraft increased the pressure for longer runways. Upon facing limits to expand their original airports to tap growing demand, some cities created multiple airport systems: the original, with smaller facilities and closer to the city center dealing with regional flights, and newer and larger airports farther away from the city center, dealing with long distance flights.

Despite the availability of larger airport facilities for long distance flights, some central airports serving the same metropolitan markets are busier than ever. This causes negative impacts as their surrounding neighborhoods are fully urbanized and densely populated. Together with real estate development pressures, these high population densities within the area of influence of either central or non-central airports lead to neighborhoods that are less compatible with airport activities.

This article addresses the case of São Paulo, Brazil, a city with 12 million people in a metropolitan area totaling 22 million, served by two large commercial airports: Congonhas (22 million passengers in 2019) and Guarulhos (46 million passengers in 2019). A georeferenced survey mapped population densities based on 2010 Census and new housing development from 1985 to 2013 on an Alignment Radial Model (ARM) model, indicating that urban development in São Paulo is in disregard of its airports' runway alignments. Evidence shows that the same urban development struggle against Congonhas in the past is on-going in the vicinity of Guarulhos airport, already surrounded by urban development and unable to expand its runway systems, restricting capacity of São Paulo's airports system. These facts put further challenges both for airport and urban planners to increasing São Paulo's airport capacity.

2. BUSY CENTRAL AIRPORTS

The increasing distance of new airports from the center of the cities they serve has been subject of a study in the past, both in the case of a new airport replacing an older one, and on the case of the new airport forming an airport system along with the original airport (Werneck de Oliveira, 2019).

Many airport systems are formed by a hegemonic airport and smaller reliever and or competing airports, such as London, Los Angeles and Moscow. There are also many airport systems where the secondary airport is a smaller airport dedicated to the traffic of Low Cost Carriers (Calder, 2003). On the other hand, there are 14 airport systems in which a central airport movements more than 10 million passengers per year (MPax/y) and one or more complementing airports are less hegemonic in terms of passengers' yearly throughput, thus creating systems where the closure of one airport would probably drive the market to a collapse or severe restriction. Thereby thus these systems depend upon the operations of their central airports as well as the other airports on their system.

Table 1 shows these systems with their cities and central airport name and 2019 MPax/y compiled by the author based on their airport authorities and/or country statistics sites, as well as the other farther or newer airport forming their airport systems.

Out of these 14 airport systems, Tokyo and Tehran are the only ones with their newer and farther away airports processing less yearly passengers than their older, original and smaller, more central airports, although this situation has happened in recent years both at Buenos Aires' and at São Paulo's airports systems. Also on very particular way, the airport systems of New York and Washington, DC, are formed by more than 2 airports, with the 3rd one being rather important to tap their metropolitan markets.

These systems' central airports are important players on their local markets but, as they were implemented many decades ago, their cities may have grown to surround them by urban development, hence creating conflicts with their neighbors (even if the airports got there first).

Table 1 Airport Systems Depending on Central Airports and their Passengers Patronage (2019)

City	*Airport*	*MPax/y*	*Airport*	*MPax/y*
Tokyo	Haneda	87.4	Narita	42.4
Shanghai	Hong Qiao	45.6	Pudong	76.2
Bangkok	Don Mueang	41.3	Suvarna-bhumi	65.4
Paris	Orly	31.9	Ch. De Gaulle	76.2
New York(*)	La Guardia	30.7	John F. Kennedy	62.3
Seoul	Gimpo	25.4	Incheon	71.2
Washington (*)	Reagan-National	23.2	Dulles	23.8
São Paulo	Congonhas	22.0	Guarulhos	46.2
Chicago	Midway	20.2	O'Hare	81.8
Osaka	Itami	16.5	Kansai	31.8
Dallas	Love Field	16.2	Dallas-Fort Worth	71.6
Tehran	Meharabad	14.3	Iman Khomeini	7.4
Houston	William P. Hobby	14.1	Georg Bush Intercont'l	43.8
Buenos Aires	Aeroparque Jorge. Newberry	12.3	Ezeiza-Ministro Pistarani	12.7

(*) New York System also depends on Newark-Liberty (46.2MPax/y in 2019) and Washington's also depends on Baltimore-Thurgood Marshall (26.4MPax/y in 2019

3. THE CASE OF SÃO PAULO AIRPORT SYSTEM

São Paulo is the largest city in the Southern hemisphere. It has 12 million people, and its metropolitan area has 22 million people (IBGE, 2022). The city's Gross Domestic Product (GDP) was US$ 217 billion in 2015 (10.8% of Brazil's GDP), while the metropolitan area's GDP was US$ 352.3 billion - 17.6% of Brazil's 2015 GDP (SEADE, 2018). Figure 1 shows a map of São Paulo's Metropolitan area and its insertion in São Paulo State and Brazil with its 2 commercial airports.

São Paulo has immense social disparities: 18.9% of the metropolis' dwellers lived in slums in 2010 (IBGE, 2013). It is among the largest cities hampered by severe housing deficit (Davis, 2006). On the other hand, it hosts the world's 2nd largest helicopter fleet, which Graham and Marvin (2001) call "the ultimate commute". On the edge of the 20th century, it was an example of a networked city for the wealthy, resulting in social exclusion (Silva, 2000) of those who Harvey (2012) calls the "disadvantaged".

São Paulo opened its first airfield – Campo de Marte, 3 km north of the city center – in 1920. In 1929 a severe flood had it halt operations for four months. In 1932 a revolution attempt led federal forces to bomb it, resulting on its closure until 1934. At that time, state-of-the-art aircrafts such as the Junkers-52 and the Douglas DC-3 already called for paved runways (Mello, 2006).

Due to the constant flooding of Campo de Marte, in 1936 the privately-owned "Auto-Estradas" Real Estate Development Company opened a new, public aerodrome 9 km south of the city center. The new aerodrome, named Congonhas, soon received paved runways and was accessible by a paved toll road (also owned by "Auto-Estradas"). The company also had the right to develop most of the surrounding neighborhoods (Santos, 1985). The earlier zoning ordinances treated the airport itself as an exceptional case within local zoning, as its vicinities were dedicated exclusively for residential development (Feldman, 2005). Early, dispersed industries nearby Congonhas would later be replaced by high rise buildings of *Moema* neighborhood. Therefore, 30 years after opening, Congonhas airport was surrounded by urban sprawl, mostly residential development (Beiguelman, 1996).

Until World War II, Congonhas processed 50,000 passengers per year in 5,000 flights. In the 1950's, the number of passengers increased to 1.5 million per year, with 91 thousand flights in 1959. In 1981 it processed 6.2 million passengers, 134.5 thousand flights and 69 thousand tons of cargo (Mello, 2006).

The combination of its relatively short runway (1,940 meters) and high elevation (802 meters) prevented larger jets to operate long-distance flights. Most international passengers from São Paulo heading abroad had to fly to Rio de Janeiro to change planes to long-distance flights there, or had to use the Campinas-Viracopos Airport, operational since 1960, but located 90 km away.

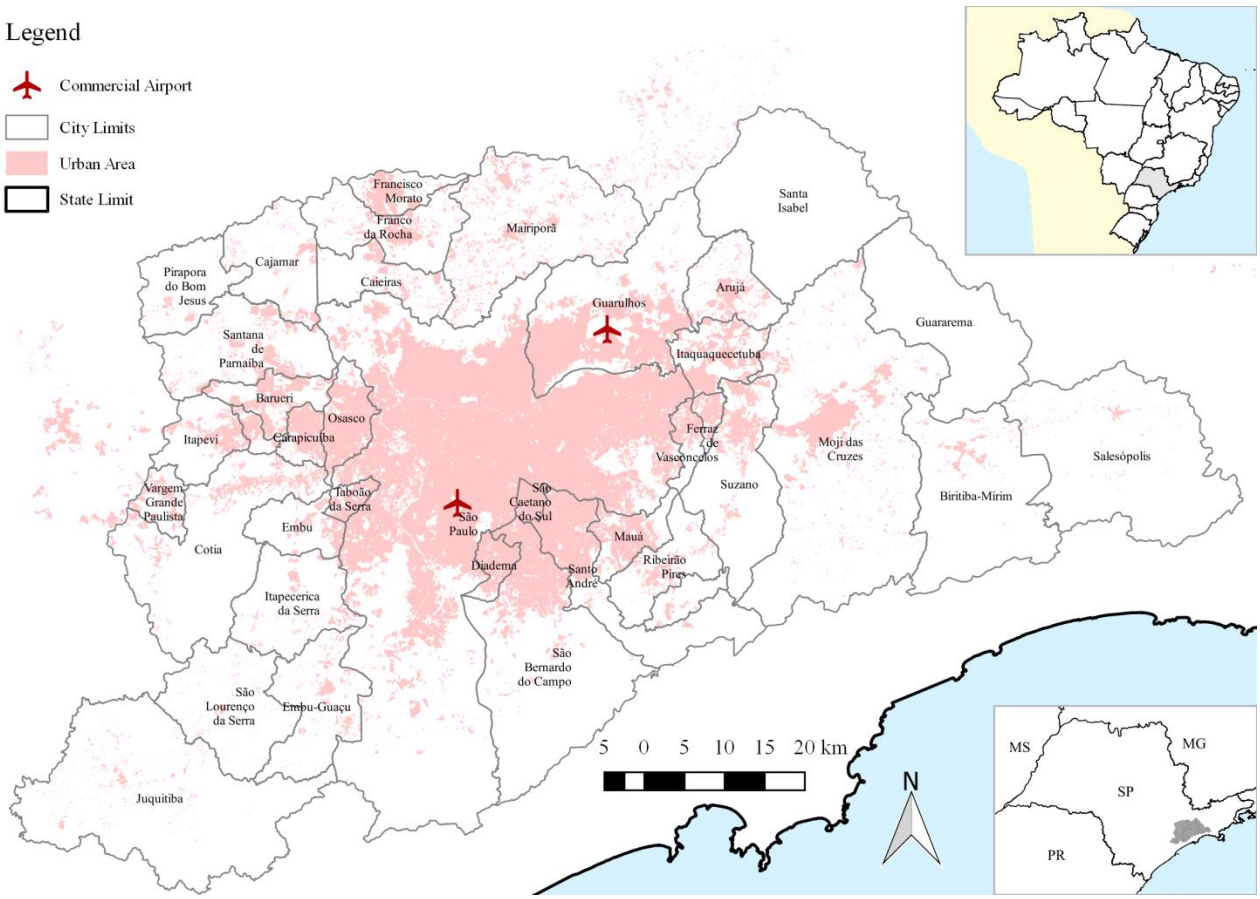


Figure 1: São Paulo Metropolitan Area and its Insertion in São Paulo State and Brazil

Thus, an international airport was planned for the city as Congonhas' runways could no longer be extended. After a poorly documented (Santos, 1985) but surprisingly pluralistic debate during military ruling in Brazil (CONDEPHAAT, 1978), the site adjacent to São Paulo Air Base was selected to develop the current São Paulo-Guarulhos International Airport, which opened in 1985, 25 km northeast of São Paulo's city center (GRU-Airport, s.d.).

Nevertheless, the city continued having two airports with commercial operations, which had their traffic systematically growing over the past three decades. Figure 2 shows the evolution of increasing passengers processed by the two commercial airports of São Paulo altogether, from 1981 to 2017.

It is worth noting that after the opening of Guarulhos Airport in 1985, most flights were transferred to it and Congonhas remained a rather idle regional airport. However, domestic flights to/from Congonhas were soon again scheduled to nearly all Brazilian major cities, allowing passengers flying from South to North or Northeast of the country changing planes at Congonhas instead of Guarulhos. As a result, from this domestic hub-like structure at Congonhas rather than at Guarulhos, from 2001 to 2007, the former's throughput surpassed that of the latter. Figure 3 shows the evolution of passengers processed by both airports from 1981 to 2017.

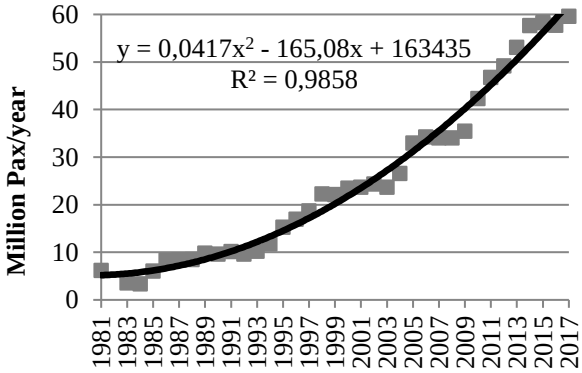


Figure 2: Passengers Processed by São Paulo's Two Commercial Airports, 1981-2017

In July 17, 2007, a fully-loaded and fueled Airbus A-320 overshot Congonhas' wet and slippery runway when landing and crashed onto a building adjacent to the airport, killing 187 people on board and 12 on the ground (ASN , 2022). This led to new restrictions regarding the use of the runway length, maximum pay-load,

with the prohibition of connections and long distance domestic flights to/from Congonhas.

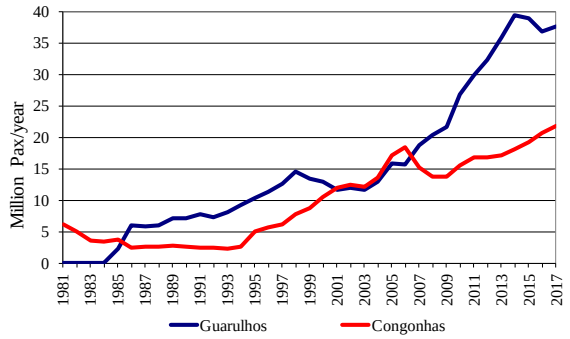


Figure 3: Passengers Processed by São Paulo's Congonhas and Guarulhos Airports, 1981-2017

During the boom of Brazilian civil aviation growth from 2004 to 2013, Guarulhos Airport took the lion's share in São Paulo's area, while Congonhas maintained growth at lower pace. Due to the Brazilian economic demise since 2015, however, Guarulhos' patronage literally diminished, while Congonhas was the country's only airport recording yearly growths.

On the other hand, Brazil's economy recovered slightly in the following years, and aviation kept growing, especially the passenger and aircraft movements of São Paulo's airports. While experiencing economic and airports' patronage growth so does real estate development in the cities they serve.

Given that Congonhas airport was built in order to sell urban plots around it, the main objective of this study was to evaluate if indeed a culture of building residences around airports has been established in São Paulo, by comparing commercial real estate development indicators with formal and informal self-construction and shanty towns (slums) both in the alignment and off from the alignment of São Paulo's two Commercial airports – Congonhas and Guarulhos International.

4. METHODOLOGY

Population densities both in the runways' alignment and off from it were surveyed based on the Brazilian 2010 (most recent currently available) official Census (IBGE, 2010). The evolution of new housing, Real estate development set for sale from 1985 to 2013 was based on a database by the Center for Studies of the Metropolis (CEM, 2018), not including self-constructed houses nor shanty or even brick-built subnormal slums which houses 18.9% of the metropolitan population (IBGE, 2013).

Mapping was applied around São Paulo's Congonhas (central) and Guarulhos International (non-central) airports' sites. It was decided not to map the city's general aviation airport (Campo de Marte) due to its relatively smaller size and its relative proximity with both Congonhas and Guarulhos airports.

For the mapping, an Alignment Radial Model (ARM) was applied, evolving from a previous methodological test (Werneck de Oliveira, 2018), but employing Geographical Information Systems (GIS) tools and considering runway alignment, as aviation's main negative impact – aircraft noise – is more linear along flight paths than radial. Hence, the ARM was phased on a 45° angle from the runway alignment, thus forming two "bow-tie" shapes: one set (two quarter of circles) aligned to dominant runways (both headings); the other set (two converse quarter-circles) dis-aligned (sideways) to the runways.

Off from the center of each airport site, a series of concentric circles were drawn at every 2 km, from the center up to 10 km. Each circle and/or ring was divided in 3.14 km^2 "*iso-areas*". The inner circle/first ring (0-2 km) has 4 "*iso-areas*", the second ring (2-4 km) has 12, the third ring (4-6 km) has 20, the fourth ring (6-8 km) has 28, and the fifth and last, outer ring (8-10 km) has 36 "*iso-areas*".

This totaled 100 "*iso-areas*" or sectors with 3.14 km^2 each for the two airports, half aligned to the runway headings and half sideways to it. Congonhas' runways headings are 17/35 and Guarulhos' are 09/27. Both airports have two parallel runways, but too close to each other, not allowing independent and/or simultaneous operations. The ARMs were thereby centered amid their runways.

Brazilian Civil Aviation Regulation (RBAC) number 161 (ANAC, 2019)suggests a buffer "area of influence" where noise levels up to 75 dB and 65 dB are tolerated and hence indicate compatible and non-compatible land uses within them. This was, however, dropped as this regulation includes somewhat small areas within noise restrictions (*e.g.* less than 1 km from each runway end for 65dBa).

Specific layers were developed on GIS software (ArcGIS version 12 for "cuts and joins" and QGIS version 2.18.21 for mapping) using SIRGAS 2000 (UTM23S) reference for the airports' site limits, their runways' alignment, their coordinates in latitude and longitude, and the ARMs with the "*iso-areas*".

Geo-referenced data from the Brazilian Population Census of 2010 - population per Census district areas (IBGE, 2010) generated another layer, while data from the CEM (2018) regarding new residential market real estate development from 1985 to 2013 generated yet another layer (weighted for total residential units rather than for total enterprises set for sale in the market, as these include many high-rise buildings, with multiple residential units in one enterprise). Unfortunately, no similar, georeferenced data from 2014 onwards was identified.

The number of residential units set for sale in the market was grouped and analyzed using dynamic tables' tool at MS Excel® spreadsheets with binary coding (1 = aligned; 0 = dis-aligned to runways). It is friendlier and faster to group data in the aligned and dis-aligned "*iso-areas*", allowing faster decision-making for the mapping, provided the code of the attribute table is always preserved to allow proper mapping when back to GIS software. Real estate development data were gathered in periods as follows: 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009, and 2010-2013 (the only group with 4 years instead of 5).

5. RESULTS

Figure 4 shows the yearly distribution of number of residential enterprises and residential units reaching the market from 1985 to 2013, showing often coinciding peaks and valleys. The average number of residential units per enterprise is 57.07, with a Standard Deviation of 11.69 units.

The overlay of the ARM and population density data from official census (IBGE, 2010) allows verifying if this variable depends on the runway alignments of these two airports. These overlays are illustrated in Figure 5, which shows the densities of the Census' Districts (practically always smaller than the "*iso-areas*", thereby resulting quite higher density peak-values).

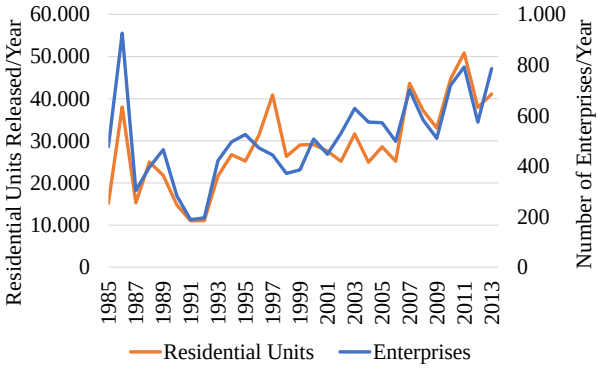


Figure 4: Annual Evolution of New Residential Enterprises and Units in São Paulo's Two Airport's Influence Areas, 1985-2013

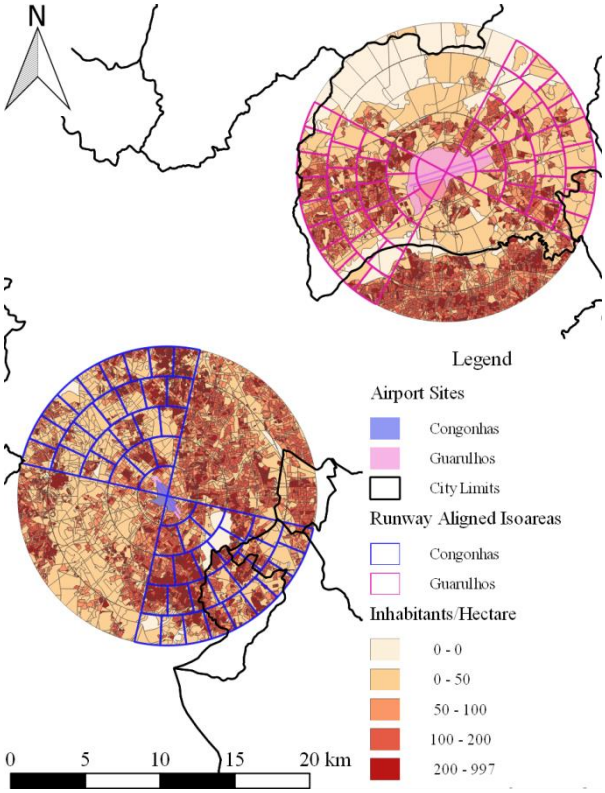


Figure 5: Overlay of ARM and Population Densities per Census Districts Aligned and Dis-Aligned with Congonhas and Guarulhos Airports Runways

The aligned and dis-aligned "bow-ties" and the ARM allows viewing how population density varies with runway alignment and distance (0-10km) from each airport site center, by "*iso-areas*" and Census Districts.

The other variable herein studied – the number of new residential units (houses and/or apartments) set for sale on the local market from 1985 to 2013 – has its overall statistics shown in Table 2. In this period, approximately half a million new dwellings were built and set for sale on the local real estate market within a 10 km-radius influenced by São Paulo's two commercial airports (85% around Congonhas and 15% around Guarulhos Airport).

Table 2: Number of New Residential Units (Houses and Apartments) Built and Set for Sale in the Market within the 10 km Radius from São Paulo's Commercial Airports, 1985-2013

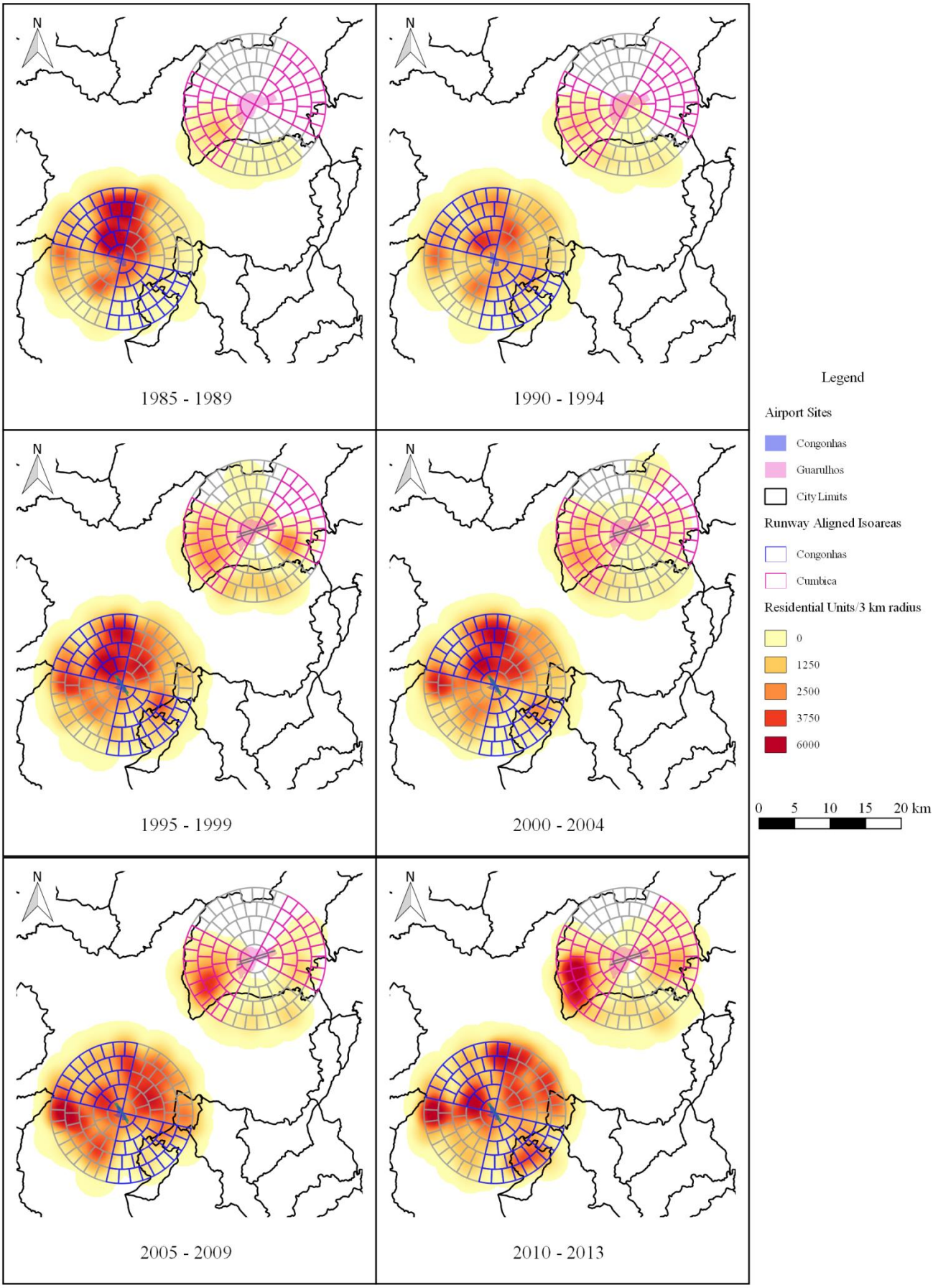
Airport	Runway	Distance from City Center		Period						Total
				1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2013	
Congonhas	Aligned	R1	0-2 km	2,140	705	833	801	1,566	745	6,790
		R2	2-4 km	10,103	6,086	8,086	7,017	4,978	6,101	42,371
		R3	4-6 km	6,413	5,151	8,360	7,058	5,363	6,386	38,731
		R4	6-8 km	8,379	4,180	11,327	9,445	6,349	5,515	45,195
		R5	8-10km	7,457	5,397	8,747	8,384	8,570	13,350	51,905
		Subtotal		34,492	21,519	37,353	32,705	26,826	32,097	184,992
	Dis-Aligned	R1	0-2 km	1,522	1,014	2,142	1,106	2,166	2,350	10,300
		R2	2-4 km	6,211	4,470	6,418	6,514	5,870	6,604	36,087
		R3	4-6 km	8,872	6,899	10,919	10,356	13,184	9,041	59,271
		R4	6-8 km	4,856	4,731	9,308	8,265	17,612	10,597	55,369
		R4	8-10km	8,334	7,230	9,508	12,308	15,570	22,136	75,086
		Subtotal		29,795	24,344	38,295	38,549	54,402	50,728	236,113
	Congonhas Total			64,287	45,863	75,648	71,254	81,228	82,825	421,105
Guarulhos	Aligned	R1	0-2 km	0	0	0	0	0	0	0
		R2	2-4 km	0	0	244	188	500	370	1,302
		R3	4-6 km	512	414	4,827	2,206	2,794	3,601	14,354
		R4	6-8 km	994	562	2,738	2,277	5,572	10,140	22,283
		R5	8-10km	380	1,282	2,291	2,702	4,073	9,538	20,266
		Subtotal		1,886	2,258	10,100	7,373	12,939	23,649	58,205
	Dis-Aligned	R1	0-2 km	0	112	512	0	0	0	624
		R2	2-4 km	0	0	68	198	0	0	266
		R3	4-6 km	0	0	0	0	29	1,002	1,031
		R4	6-8 km	0	239	1,648	819	722	889	4,317
		R5	8-10km	418	949	3,049	1,182	1,810	2,131	9,539
		Subtotal		418	1,300	5,277	2,199	2,561	4,022	15,777
	Guarulhos Total			2,304	3,558	15,377	9,572	15,500	27,671	73,982
Grand Total				66,591	49,421	91,025	80,826	96,728	110,496	495,087

Figure 6, in the sequence, shows a series of heat maps illustrating how the number of new residential units set for sale by real estate developers evolved along the several quasi-five-year periods, and how they geographically distribute between the surroundings of Congonhas and Guarulhos airports, considering the "bow-ties" aligned and dis-aligned with their respective runways within the ARM. These heat maps were developed weighting the number of total residential units' year by year, summed for the quasi-five-year periods, with a buffer rendering of 3 km from the densest points of the geo-referenced residential enterprises. They were all classified into five levels of densities, which limits have been arbitrarily defined as shown on the legend of Figure 6.

It is noteworthy that this data refers to real estate developers and does not include self-construction, neither in normal, urbanized urban plots by privateers, or self-construction of new shacks in slums. Formal real estate development concentrates on the central alignments of the runways of both airports (São Paulo's center is Northwest of Congonhas airport and Guarulhos center is west of Guarulhos airport).

It is also important to note that here are high population densities on the peripheral alignments of both airports' runways (Southeast of Congonhas and East of Guarulhos), indicating that these areas were densely populated in 2010, although they had nearly no commercial real estate development since 1985, indicating the presence of informal and eventually subnormal dwellings (slums).

Figure 6: Evolution of Heat Maps of New Residential Units (5-year Periods) Overlay to the ARM for São Paulo's Congonhas (Central) and Guarulhos (Non-Central) Airports



The population density within the 3.14 km^2 "*iso-areas*" show dense areas aligned with Congonhas' runways (Figure 5). There is a dense "*iso-area*" just 2-4 km northwest of the runway, which is due to vertical, multiple-stories buildings in "*Moema*" neighborhood, while in the south, the higher density reflects intense partitioning of plots into small areas for single- or multi-familiar sub-normal housing, often in self-constructed shacks in slums or shantytowns from 2 km to 6 km south of Congonhas airport. The dense "*iso-areas*" 6-10 km north of Congonhas coincide with vertical housing development in the expanded city center, surrounding "Paulista Avenue", which spreads towards east (into the "bow tie" dis-aligned with Congonhas' runways) in lower densities.

Guarulhos Airport neighborhood has low density within 2-4 km aligned with its runways because its site is significantly larger than Congonhas'. West of the runway, though, there is a high-density "*iso-area*" due to slums, north of Guarulhos' city center, where moderate densities were observed in 2010. East of the runway there are low to medium density "*iso-areas*" due to urban segmentation caused by the airport itself. The higher density "*iso-areas*" in the south (dis-aligned to the runways, 6-8 km, and 8-10 km radius) are due to a mix of slums and vertical urban development in east-northeast end of São Paulo – a clear urban expansion area (unrelated to the airports). North of Guarulhos airport site lays an environmentally protected area ("Serra da Cantareira" forested hills) not yet encroached by urban development – but threatened by urban expansion with subnormal housing of low-income families.

6. CONCLUSIONS

The use of the ARM suits the purposes of this study by allowing visualizing land use up to 10 km radius from the airports' centers. It is a clear means to comparing densities and new housing heat maps as aligned and dis-aligned to the airports' runways. An imaginary straight line from the runways allows considering fully aligned "*iso areas*" and moderately aligned ones, providing subsidies for air traffic controllers to develop Noise Abatement Departure Procedures (NADP) in optimized routes (although every route out of Congonhas airport flies over populated areas). It also contributes for urban planners to better regulate zoning in order to prevent increasing residential densities in noise-sensitive areas aligned with these large airports' runways.

However, evidence shows that an urban sprawl process very similar to that which surrounded São Paulo's older and more central Congonhas airport is being replicated at the vicinities of newer and more peripheral Guarulhos international airport.

Evidence supporting such finding is two-fold. First, the evolution of real estate formal development illustrated by consecutive quasi-five-years periods with heat maps, especially towards cities' centers alignments of both airports' runways (Figure 6). Second, from mapping population densities based on the 2010 Census indicating high population densities also at the opposite runway alignments towards the peripheral areas of São Paulo and Guarulhos Municipalities, where self-constructed and eventually subnormal urban development predominates (Figure 5).

On one hand, this obviously prevents both airports to expand, especially their runways capacities (Guarulhos airport master plan anticipated the construction of a 3rd runway, but since the turn of the century this is considered not feasible, as it would require the involuntary resettlement of no less than 5 thousand families). On the other hand, allowing continuous augmentation of population densities aligned with these airports runways tends to fuel more conflict, as the number of people affected by aircraft noise increases substantially. Thereby, such evidence indicates that the conflictual fate around Congonhas airport may well be replicated around Guarulhos international airport, putting additional challenges both for airport operators and for city planners at São Paulo and Guarulhos municipalities, eventually limiting the prospects of capacity expansion of the São Paulo Metropolitan Area airports capacity. Expanding the survey to newer-than-2013 data (not yet available) could reinforce this conclusion.

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