THE INCREASING DISTANCE OF AIRPORTS FROM CITY CENTERS: AN EXPLORATORY ANALYSIS OF AIRPORT REPLACEMENT AND MULTIPLE AIRPORT SYSTEMS' CASES

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ABSTRACT

Urban sprawl renders many airports unable to expand. While many urban-surrounded airports were closed to commercial traffic, other in such condition remain open and busy, thus forming multiple airport systems with new, larger airports, located far from cities' centers. This paper explores and analyses the historical trend of increasing distances of newer, larger airports from city centers as compared to the original ones. Despite widely spread distance ratios, evidence shows that new airports tend to be farther away from the center of the cities they serve when replacing original ones more often than when forming multiple airport systems.

Keywords: Airports, Urban Sprawl, Distance from City Center, Airport Replacement, Multiple Airport Systems.

1. INTRODUCTION

Along time, many airports serving large cities became cramped and unable to grow due to urban sprawl around them. Due to this land use conflict affecting safety and increasing the nuisance of aircraft noise, many original airports were closed to commercial traffic and converted to general aviation or military use. Whenever demolished, these former airport sites rendered urban land use redevelopment. In other cases, the cities and their airport authorities chose not to close their original, growth-hampered airports but kept them operational for commercial traffic together with the newer airport, built in more remote urban fringes.

The objective of this article is to develop an exploratory analysis of the apparent eviction of airports by the cities they serve, comparing the distances of their original airports, either closed or still commercially operational, with newer airports (replacement or system forming ones). It identifies several original, old airports that were closed to commercial traffic and replaced by new airports, as well as various cases in which such original (then central) airports remain open to commercial traffic and are complemented by the newer and farther airport, thus forming multiple airport systems serving the same city or metropolitan area.

The hypothesis that cities evict their airports to farther urban fringes is partially confirmed by plotting the increasing distances of airports from the cities' centers along time. This is true in the case of airports replacing closed ones, but the ratio of distances between new airports and those remaining open show a less defined distribution along time, rendering poorer mathematical trends (correlation R^2) of increasing distances over time. Even so, the farther distance of replacement and system forming airports since 1960 (the dawn of the jet age) is remarkable. This imposes new challenges for urban planners and airport authorities, as airport sites tend to be located farther away, with fewer cases of airports located as close to city centers as they used to be before the 1960's.

The article presents a literature review on cities that have evicted their airports (driven by obsolescence, safety, and urban insertion), either replacing original airports or forming airport systems. It then describes the methods employed (data survey, study of distance ratios and their statistics). The results are briefly described (summarized in Tables and Figures) and discussed, leading to the conclusions.

2. CITIES EVICTING THEIR AIRPORTS

Early airports used to have very simple structures and their landing strips used to be circular grass fields (Blankenship, 1974; Szurovy, 2003). They handled pioneer aircraft made of wood and metal, with capability limited to 10-20 passengers (Komons, 1989). Soon after, heavier, all-metal and profitable aircraft (e.g.: the Douglas DC-3) appeared in commercial routes (Kofman, 2004). With increased overall power and weight, airports' runways started to be paved with cinder, asphalt, concrete and even metal plates, oriented against dominant wind directions, with multiple alignments (Munera, 1970).

Urban utopias presented a view of approaching cities (Fishman, 2016), depicting aircraft landing strips amid high-rise buildings, such as the "Ville Radieuse" by Le Corbusier, in 1925 (Anthony, 1966), or meshed into low density suburbs, like the "Broad Acre City" of Frank Lloyd Wright, in 1935 (Nash, 1996).

Airports soon began to have dedicated passenger terminal buildings, such as Floyd Bennett Field (New York), Croydon (London) and Le Bourget (Paris, soon replaced by Orly for commercial aviation services). At the golden age of seaplane for overseas long-haul travel, seaplane stations had a sea-side harbor and at times a land-side set of runways, such as Singapore's Kallang airport. Current Miami City Hall building used to be former Pan Am seaplane base Passengers Terminal, while fully land-based airports such as Chicago Midway, Dallas Love Field and Los Angeles Mines Field (current Los Angeles International) were soon developed (Szurovy, 2003).

Airports started to worry urban planners from the beginning. Framing frame them within typical urban zoning (RAU Jr., 1930), trying to create compatibility of surrounding land uses (Opperman, 1938; Albers, 1940) targeted preventing functional and safety conflicts.

With the end of World War II, thousands of former military transport aircrafts became available to expand civil aviation. Several military air bases became redundant by peace-time, allowing the development of new civilian airports, such as London-Heathrow.

The availability of heavier and more powerful aircraft rendered some pre-War airfields obsolete, leading to their early closure. This was the fate of New York's Floyd Bennett Field, Paris-Le Bourget, London-Croydon and Singapore-Kallang airports. In the aftermath of World War II, aviation improvements' optimist views also considered potential conflicts with urban development (Ogburn, 1946).

In 1948, airports became a geopolitical asset when a Soviet-driven road, rail and waterway blockade curtailed all surface access to West Berlin. The solution came through the Berlin Airlift, which supplied the city with everything it needed, surpassing 1 million tons of cargo in less than a year. This included rebar and cement to build Tegel airport's runway to relief congestion of Tempelhof, then the sole airport serving West Berlin (Giangreco and Griffin, 1988).

In the early 1950's a series of three aircraft accidents took place in the environs of Newark's Liberty Airport in the United States. On December 16, 1951, a Curtiss C-46 crashed 4 km from its runway, killing 56 aboard and badly hurting people on the ground. On January 22, 1952, a Convair CV-240 crashed 5.5 km from the same airport, killing all 27 on board, plus 7 on the ground, in the city of Elizabeth, New Jersey. On February 11, a Douglas DC-6 crashed 2.5 km from Newark's runway (in the same city), killing 29 of the 53 aboard, plus 4 people on the ground (ASN, 2019). These events made the headline covers of *Life* and *Newsweek* magazines, giving safety around airports a large visibility (Gordon, 2004).

United States' president Harry Truman quickly addressed the issue, calling the Presidential Airports Commission on February 20, 1952. In 90 days, the three-membered group interviewed 75 municipal government mayors and managers and visited 30 airport sites, developing a report called "*The Airport and Its Neighbors*". Although they recognized the

anxiety caused by accidents involving ground casualties, they clearly indicated that the airports *versus* cities conflict would soon transfer from safety around airports to the noise nuisance, as the emerging generation of civil jet aircraft would require much longer runways, and much flatter approach glides and take-off paths (Doolitlle *et al*., 1952).

These were soon to be new challenges to urban planners, as the construction of new, much larger, and remotely located airports was imminent (Dinning, 1953). Furthermore, in 1957 for the first time the total transport production of civil aviation (passenger X miles) in the United States surpassed the output of buses and trains (Cherington, 1958).

Hence, at the dawn of the jet-age, newly-needed jetports triggered an array of airports as typical "megaprojects" (Altshuler and Luberoff, 2003), built in less densely occupied fringes of large cities but soon attracting urban growth towards them. Virtually a decade later, the conflict between urban sprawl and busier airports processing noisier jet aircraft was evident (Hammarskjöld, 1967). But city-cramped airports were not necessarily closed down: many cities decided to keep their original airports handling regional flights, and dedicated their new airports for international, long-distance flights (Blankenship, 1974), thus creating "airport systems" (De Neufville and Odoni, 2003).

This had implications on air carriers' structures, as national "flag-carrier" companies were first challenged by "charter airlines" and more recently by Low Cost Carriers (LCC) (Calder, 2003). Such phenomena further increased the formation of airport systems, as some LCC could not secure access to busier airports and soon started to explore smaller regional airports in the vicinities of larger cities, at times much farther away than the original airports (De Neufville, 2006; Derubber *et al*., 2010; Warnock-Smith and Potter, 2005).

In the meantime, urban population grew more than ever (there are now more people living in cities than in rural areas), with anticipated further growth of urban population (and decrease of rural population from 2025 onwards) worldwide, mostly concentrated in poorer regions' cities (United Nations, 2015).

It is intuitive that new airports are located farther away from city centers, but evidence showing such trend is worth checking, as it might impose new restrictions on airports' operations (Upham *et al*., 2004; Suau-Sanchez *et al*., 2011) and new challenges to urban planners (Stephens *et al*., 2010; Ryerson, 2016).

3. METHODS

A survey of large airports (processing more than 1 million passengers per year) was conducted in statistical records of countries' and airport's authorities' websites as well as on specific airport databases (Airports Base, 2019), focusing on metropolitan areas with more than one commercial airport along time. These airports' historical development was analyzed, identifying their opening and closure dates.

Two groups of information were produced. The first yielded a table with airports that were closed to commercial traffic and their distance to their cities' centers, the year of the transition to the new airports, and the predominant reason of their closure. It includes information regarding the new use of their sites (which can be still an aerodrome for general aviation or military bases, or different urban development after the original structures were demolished), the replacement (new) airport name, their respective distances to the same city center, and their recent patronage in terms of millions of passengers per year (MPax/year).

The second group includes the cases of original airports that remain open for commercial air traffic despite the opening of newer, farther away airports in more distant urban fringes of the same metropolitan area. This second table includes the year of opening of the original airport and of the newer one, their names and the distance between them and the main city they serve.

A spreadsheet with airports' opening dates and distances was prepared. Airports were grouped in four different categories: (1) original airports that were closed to commercial traffic; (2) airports replacing those original upon their closure; (3) original airports that, despite cramped by urban sprawl, remain open to commercial traffic to-date; and (4) additional, new airports forming the airport systems, either driven by airport capacity limits or by market

opportunities where LCC unable to operate from more dynamic and larger metropolitan airports exploring them, thus forming systems with smaller, regional and once idle ones.

A graph of these four categories' pairs of dates and distances was developed, identifying the categories from the two tables showing the four sets of data. Eventually, some airports of category 2 replacing closed airports of category 1 became central airports on category 3 dully complemented by multiple systems' newer and larger airports of category 4.

An additional graph shows the dispersion of the distance ratio (km from city center to the new airports divided by km from city center to the original airports): the first graph is for replacement airports *versus* closed early airports; the second graph is for airports forming multiple airport systems, as the original airports remain in commercial operations while the newer airports handle most of the international and long-distance flights.

4. RESULTS

Table 1 shows the list of original airports which were closed for commercial traffic and replaced by newer airports, with their respective transition dates, distances from city centers, main motive or reason for their closure, current land use of the former commercial airport site, replacement airports' names, and their distances from their respective city centers.

Table 2 shows the list of original airports that despite becoming too central and surrounded by urban sprawl, are still operational for commercial traffic, even though they are complemented by larger, newer and more remotely located airports. It shows the year of opening of both the original and the newer airport (the leading column in chronology) and their distances from their respective city centers. It also shows recent yearly patronage data (MPax/year) of both airports in order to identify how many of these central airports remain busy and important for their cities' airport system, taking a significant part of their markets.

In the sequence, Figure 1 shows the graph of the four airports' categories opening dates (regardless of their eventual closure dates) and the distances of all such airports from their respective city centers. The graph does not include airports closed due to wars (Nicosia, in Cyprus, in 1974, Sana'a in Yemen, and Donetsk, Ukraine, both in 2014) as these airports were not actually replaced by new ones (although nearby cities opened airports after the Cypriot civil war was over). Former Gaza Strip's Yasser Arafat Airport was destroyed by Israeli forces during the 2011 Intifada, but it was not included in the survey as there are no records of its patronage.

Groupings of the four categories were formed as follows: (a) Closed Airports and Replacement Airports; (b) Central Original Airports and System Forming Airports. Both had their distances from their respective city centers computed in relative ratios (km/km).

The former (a) grouping ratios are plotted as blue dots in Figure 2, ranging from zero to 20 times the distance (Replacement/ Closed Airports), and cover from 1940 to 2020 (as airports' replacement ranges from 1940 to 2019). The latter (b) grouping ratios are shown as red dots, with values ranging from zero to 16 times the distance (System Forming/Original Central Airports), and chronologically from 1946 to 2012.

The number of airports which were closed down is quite high (39). Due to three of them having been destroyed at wars and only one being replaced so far, the number of replacement airports is slightly lower (37). The average distance of closed airports is 10.9 km from the city center (ranging from 2 to 40 km), while the average distance of replacement airports is 29.4 km (ranging from 11 to 63 km).

The number of central airports which still have commercial traffic and operate together with larger, newer airports thus forming airport systems is the lowest among the four categories of analysis (32). The number of new airports forming airport systems with them is higher (42), as there are metropolitan areas which have their airport systems with more than two airports (e.g.: London, Milan and Moscow). The original and now central airports are in average located 9.9 km from their city centers (with distances ranging from 1 to 25 km), while the average distance from city centers to newer and larger system forming airports is much larger (36.8 km), ranging from 5 to 100 km.

Table 1: Closed and Replacement Airports' Data

City, Country	Closed Airport	Dist. (km)	Year Closed	Motive / Reason	New Land Use	Replacement Airport	Dist. (km)
New York, USA	Floyd Bennett Field	18	1939	O	Park	La Guardia	13
London, UK	Croydon	16	1952	O	Of; LI	Heathrow	24
Singapore	Kallang	2	1955	O	UD	Paya Lebar	15
Maracaibo, Venezuela	Grano de Oro	5	1969	A	UnC	La Chinita	11
Dallas, USA	Greater Southwestern	12	1974	O	Airport	Dallas-Fort Worth	27
Nicosia, Cyprus	Nicosia International	8	1974	W	Derelict	Ercan (Turkish Cyprus)	13
Singapore, Singapore	Paya Lebar	15	1980	C; UI	AirB	Changi	20
Jakarta, Indonesia	Kemayoran	10	1985	C; UI	UD	Suekarno Hatta	25
Chongqing, China PRC	Baishiyi	15	1990	C; UI	AirB	Jiangbei	20
Munich, Germany	Riem	6	1992	C; UI	UD; Expo	F. J. Strauss	28
Denver, USA	Stapleton	5	1995	C; S	UD	Denver International	37
Hong Kong, China SAR	Kai Tak	2	1998	C; S; N	UD; CST	Chek Lap Kok	34
Oslo, Norway	Fornebu	7	1998	C; N	Of; UD; AR	Gardermoen	48
Austin, USA	Robert Mueller	6	1999	C; UI	UD	Austin-Bergstrom	13
Damman, Saudi Arabia	Dharhan	20	1999	Unknown	Unknown	King Fahad	15
Athens, Greece	Ellinikon	9	2001	C; O	Derelict	Eleftherios Venizelos	30
Montreal, Canada	Mirabel	40	2004	EF	AM	Dorval - P. E. Trudeau (a)	15
Guangzhou, China PRC	Bayun	5	2004	C; UI	UD; SM	Guangzhou Bayun	25
Changchun, China PRC	Dafangshen	10	2005	C; UI	AirB	Longjia	32
Hyderabad, India	Begumpet	5	2008	C; UI	AirB	Rajiv Ghandi	22
Berlin, Germany	Tempelhof	4	2008	N; UI	Park	Brandenburg (b)	18
Bangalore, India	Hindustan	6	2008	C; UI	AM; AirB; GA	Kempegowda	40
Durban, South Africa	Durban	19	2010	C; UI	AirB	King Shaka	60
Moscow, Russia	Bykovo	31	2010	UI	AM	Vnukovo	28
Mataram, Indonesia	Selaparang	2	2011	UI	Unknown	Lombok	40
Heifei, China PRC	Waisha	9	2011	C; UI	AirB	Jiayang Chaoshan	28
Kunming, China PRC	Wujiaba	4	2012	C; UI	UD	Changshui	24
Bucharest, Romania	Baneasa - Aurel Blaicu	8	2012	C; UI	GA	Henri Coanda - Otepeni	16
Cagayan de Oro, The Philippines	Lumbia	4	2013	C; UI	AirB	Langhindingan	46
Ishigaki, Japan	Ishigaki	2	2013	C	Unknown	Painushima	11
Hefei, China PRC	Lougang	9	2013	C; UI	AirB	Xinqiao	32
Quito, Ecuador	Mariscal Sucre	18	2013	S; UI	Park	Nuevo Mariscal Sucre	40
Medan, Indonesia	Polonia	3	2013	A; UI	AirB	Kualanamu	20
Doha, Qatar	Doha International	6	2014	C	Unknown	Hamad International	12
Natal, Brazil	Augusto Severo	15	2014	C; M	Air Base	S. Gonçalo Amarante	40
Sana'a, Yemen	Sana'a	13	2014	W	Destroyed	N.A.	N.A.
Donetsk, Ukraine	Sergei Prokofiev	10	2014	W	Destroyed	N.A.	N.A.
Yantai, China PRC	Laishan	7	2015	C; UI	AirB	Penglai	42
Dakar, Senegal	Yoff-Léopold Sédar Senghor	5	2017	C	Unknown	Blaise Diagne	40
Islamabad, Pakistan	Benazir Bhutto	8	2018	C; UI	AirB	Islamabad International	20
Istanbul, Turkey	Atatürk	24	2019	C	Unknown	Istanbul International	63

Motive / Reason: A = Accident; C = Capacity Restriction; EF = Economic Feasibility; M = Conflict with Military Use; N = Noise; O = Obsolescence; S = Safety Issues; UI = Urban Insertion; W = War.

New Land Use: AirB = Air Base (Military); AM = Aircraft Manufacturing; AR = Events (Sports, Music) Arena; CST = Cruise Ship Terminal; Expo = Exposition Center; GA = General Aviation; LI = Light Industry; Of = Offices; UD = Urban Development; UnC = University Campus; SM = Shopping Mall.

Other Notes: (a) Montreal Dorval / P. E. Trudeau pre-existed Mirabel Airport; (b) Berlin Brandenburg not opened yet; N.A. = Not Applicable. Abbreviated country names: USA = United States of America; UK = United Kingdom; SAR = Special Autonomous Region (of China); China PRC = People's Republic of China.

Table 2: Central Original and System Forming Airports' Data

City	Name	Year	MPax/ year	Dist. (km)	Name	Year	MPax/ year	Dist. (km)
Buenos Aires	Aeroparque Jorge Newberry	1925	13.3	2	Ezeiza - Ministro Pistarani	1946	9.7	22
New York	La Guardia	1939	30.1	13	John F. Kennedy	1948	61.3	24
Milan	Linate	1930	9.2	5	Malpensa	1948	24.7	45
Rio de Janeiro	Santos Dumont	1935	9.2	1	Galeão - Antonio Carlos Jobim	1952	15.0	15
London	Heathrow	1946	80.1	24	Gatwick	1953	46.1	47
Chicago	Midway	1927	21.4	13	O'Hare	1955	79.9	24
Paris	Orly	1932	33.1	14	Beauvais-Tillé	1956	3.8	85
Moscow	Vnukovo	1941	21.5	28	Sheremetyevo	1957	45.3	29
Toronto	Billy Bishop	1939	2.8	5	Pearson	1958	49.5	27
Beijing	Nanyuan	1915	6.5	13	Capital	1958	101.0	28
Kiev	Zhuliany - Igor Sykorski	1923	2.8	6	Boryspil	1959	12.6	34
Rome	Ciampino	1916	5.8	12	Fiumicino - Leonardo Da Vinci	1961	43.0	35
Stockholm	Bromma	1936	2.5	7	Arlanda	1962	26.8	45
Moscow	Vnukovo	1941	21.5	28	Domodedovo	1964	29.4	22
London	Heathrow	1946	80.1	24	Luton	1965	16.8	45
London	Heathrow	1946	80.1	24	Stansted	1966	28.0	68
Houston	William P. Hobby	1927	14.1	11	George Bush Intercontinental	1969	42.3	35
Milan	Linate	1930	9.2	5	Bergamo Orio Al Serio	1972	12.9	45
Dallas	Love Field	1927	15.6	10	Dallas-Fort Worth	1974	65.6	27
Paris	Orly	1932	33.1	14	Roissy-Charles De Gaulle	1974	72.2	27
Johannesburg	O.R. Tambo	1952	21.2	25	Lanseria	1975	2.0	24
Tokyo	Haneda	1931	85.0	12	Narita	1976	40.7	65
Taipei	Songshan	1936	5.9	3	Taoyuan	1979	44.9	40
Belfast	Belfast International	1922	6.3	21	Belfast City - George Best	1983	2.5	5
Belo Horizonte	Pampulha	1936	0.2	8	Confins - Pres. Tancredo Neves	1984	10.6	42
São Paulo	Congonhas	1936	22.0	9	Guarulhos - Gov. A. F. Montoro	1985	42.2	25
Medellin	Enrique Olaya Herrera	1932	1.2	3	José Maria Cordova - Etioquia	1985	8.0	20
Jakarta	Halim Pernadakusuma	1925	7.4	11	Soekarno Hatta	1985	65.9	25
London	Heathrow	1946	80.1	24	City	1987	4.8	10
Osaka	Itami	1939	15.6	10	Kansai	1994	28.0	38
Stockholm	Bromma	1936	2.5	7	Skavsta	1996	2.2	100
Brussels	Zaventen	1948	25.7	12	Brussels South - Charleroi	1997	8.0	55
Kuala Lumpur	Sultan Abul Aziz Shah	1965	2.0	22	Kuala Lumpur - Sepang	1998	58.5	45
Shanghai	Hong Qiao	1923	43.6	13	Pudong	1999	74.0	34
Oslo	Gardermoen	1998	28.5	48	Torp – Sandfjord	1999	2.8	100
Seoul	Gimpo	1942	25.1	17	Incheon	2001	62.1	50
Tehran	Mehrabad	1958	17.4	5	Iman Komeini	2004	8.8	30
Nagoya	Komaki	1946	0.9	12	Chubu Centrair	2005	11.4	35
Mexico	Benito Juarez	1928	47.7	5	Toluca - Lic. Adolfo L. Mateos	2006	0.7	40
Bangkok	Don Mueang	1924	38.3	22	Suvarnabhumi	2006	60.9	25
Orlando	Orlando International	1974	46.5	9	Orlando Sanford	2007	2.9	29
Istanbul	Atatürk	1918	64.1	24	Sabiha Gökçen	2007	31.4	35
Dubai	Dubai International	1960	88.2	4	Dubai Central Al Maktoum	2008	0.9	37
Phoenix	Sky Harbor	1935	43.3	5	Phoenix-Mesa Gateway	2009	1.5	10
Warsaw	Frederic Chopin	1934	17.8	10	Modlin Mazovia	2012	2.9	40
Istanbul	Atatürk	1918	64.1	24	New Istanbul Airport	2018	1st year	63

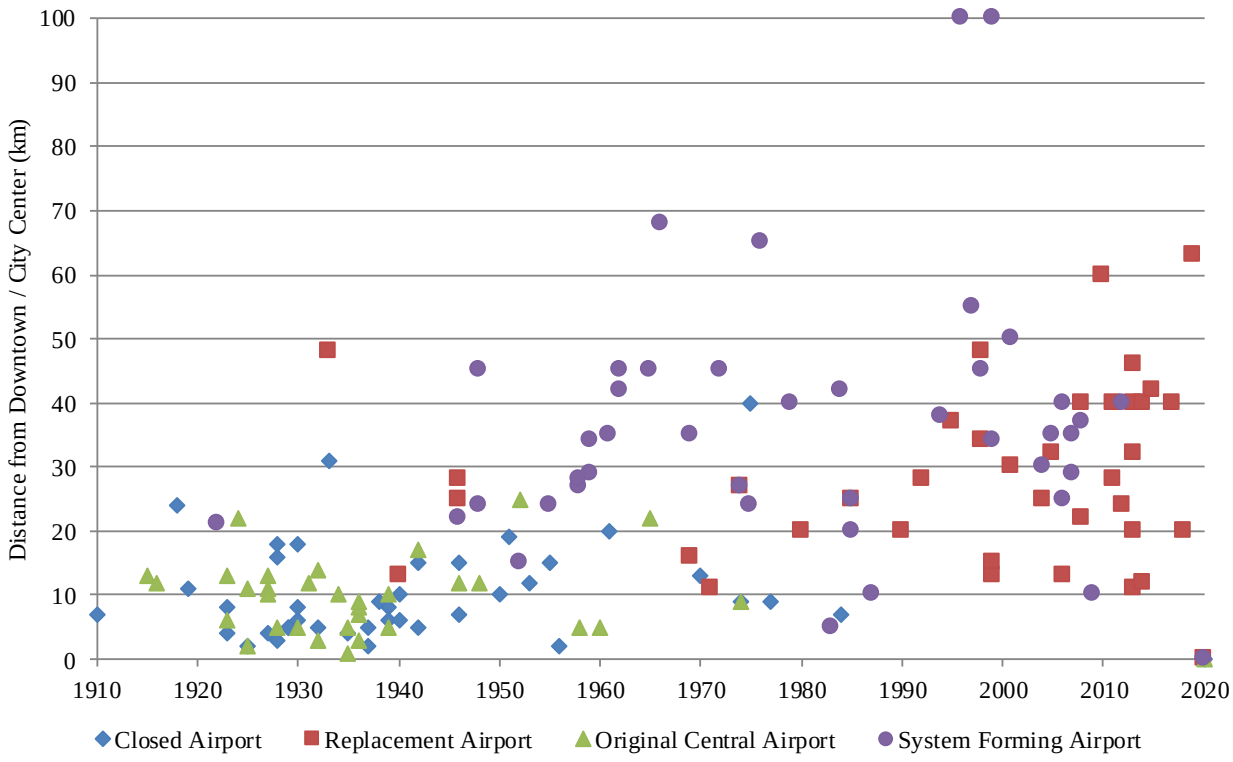


Figure 1: Distance from City Center of Closed, Replacement, Original Central, and Systems Forming Airports

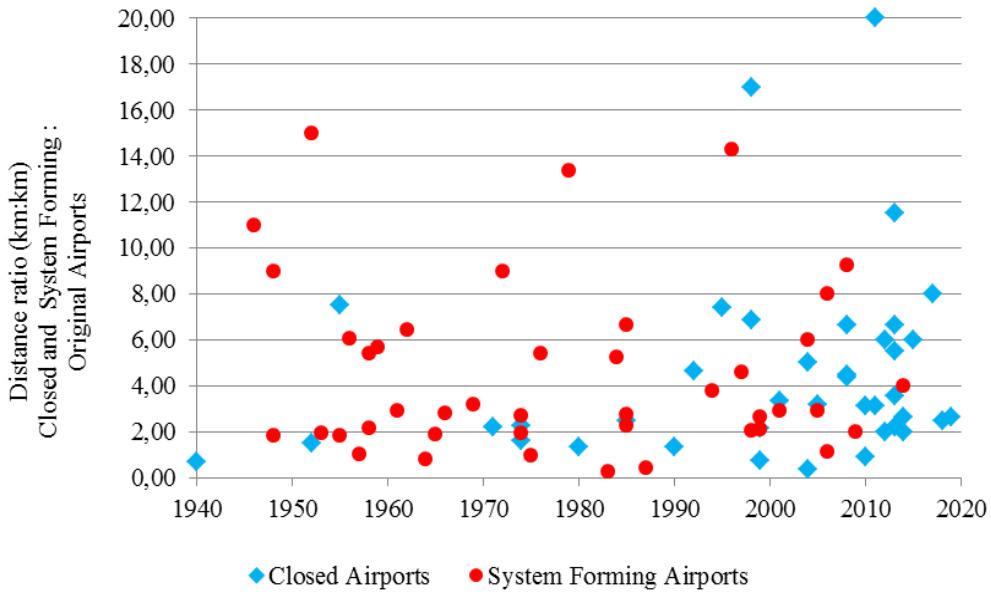


Figure 2: Distance Ratio: Replacement x Closed Airports and System Forming x Original Central Airports

5. DISCUSSION

Most early airports of the sample that closed did so due to the lack of ability to expand their capacity because of their urban insertion (a result of urban sprawl). Most were operational since the 1930's and were mostly located less than 10 km from the city center. Few of these closed airports were either farther than 20 km from the city center and/or became operational since the 1960's (coinciding with the jet age). Exceptions include Mirabel Airport, in Montreal, and some airports in China that were relatively young and even so were recently replaced.

Airports that were closed are replaced by new ones which are typically located more than 20 km from city centers and were mostly opened to commercial traffic in the past 20 years (25 of 37 opened since 1998). Most of these were "greenfield" airports, built with the clear objective of replacing older, original and urban sprawl-cramped airports that had been active for decades, since the cities they served also expanded physically and surrounded them with urban development.

Of the 32 airports that became central to multiple airport systems (eventually unable to expand their physical capacity – especially in terms of runway length), 24 (75%) process more than 10 MPax/year. Of these, 11 are the major airport within their metropolitan area and 10 are busy central airports within systems where the newer, farther airport is the major one in the metropolitan airport system. The number of somewhat smaller airports operating LCC services makes such computing challenging. In terms of distance, while the system forming airports are typically much farther from city centers, some LCC-activated former downtown or central airports make the distribution of distances and the range between system forming and original central airports quite random.

This is particularly affected by the fact that some airport systems have both their original, central airport and their newer one relatively close to the city center. Rio de Janeiro's Santos Dumont, for instance, is 1 km from downtown, while Galeão (the system forming airport of that metropolitan area) is 15 km away. The 1:15 ratio is quite high (against an average ratio of [1:]4.45 among 45 cases, with a standard deviation of [1:]3.68), but an international airport as large as Galeão being located only 15 km from the city center is rather unusual (of the 45 airports' sample, only Belfast City, London City and Phoenix-Mesa Gateway are the only ones closer to downtown – the average distance is 37.5 km, with a standard deviation of 20.3 km).

Hence, the use of distance ratios may not be as good an indicator as it is for the case of replacement *versus* closed airports, especially when considering the cases of LCC activating formerly small, remote and regional airports such as Paris' Beauvais-Tillé or Oslo-Sandefjord (Torp) or Stockholm-Skavsta (Nyköping). This is even more complex when they activate formerly idle central airports such as Milan-Linate and Rome-Ciampino, which were investment-starved since the opening of their respective system forming counterparts Milan-Malpensa and Rome-Fiumicio-Leonardo Da Vinci.

When considering solely the distance along time (graph of Figure 1), although the ample dispersion of points, subgroupings of closed airports and original central ones are clearly older and closer to city centers than subgrouping of replacement and system forming airports.

A critical factor of the methodology employed is the dependence on statements of distance from city centers. The existing, operational airports have such distance credited in websites such as AirportsBase.com (Airports Base, 2019), but in some cases, uncertainty regarding the actual city center is worth noting. Downtown Rio de Janeiro is mostly a central quartier rather than a central point. Should the center be considered slightly elsewhere, the distance to Santos Dumont airport could double from only 1 km to still a quite near 2 km, decreasing the distance ratio to Galeão airport to 7.5:1 instead of 15:1.

Furthermore, information on airports that closed many years ago is not easily found, but they allow locating their position (or the position of their remains) most of the time. A few structures of former, closed airports such as former control towers, parts of terminal buildings, and even sections of demolished runways can be traced in the internet using Google Maps and Street View tools (Google Maps, 2019), but their actual center as a reference point is long gone.

Even so, visual aspects of the ratios of replacement *versus* closed airports (blue dots in Figure 2) indicate a trend of growing distance within time, while the same does not happen in the systems forming *versus* original, central airports (red dots in Figure 2).

Further analysis on the typology of airport systems can be an interesting future step of this research. Further subgroupings could shed some light on what could become "taxonomy" of airport systems, with different

challenges to urban planners, who certainly must deal with very different situations in all these subgroupings.

A subgroup formed by central airports complemented by a much larger newer and farther airport (e.g.: Chicago Midway and O'Hare; Houston William P. Hobby and George Bush Intercontinental, and Dallas Love Field and Dallas Fort Worth) is very different from a subgroup of opportunistic regional airports being leveraged into metropolitan systems by LCC (e.g. Brussels Zaventen *versus* Brussels South-Charleroi). The first subgroup above typically involves airports quite like the subgroup of airports that have been closed and replaced in terms of urban encroachment and surrounding development by urban sprawl.

The reason why some of these airports were closed and some were not is not clear. What are the leading issues driving opportunities such as keeping central airports open (despite being unable to expand their runway lengths)? Why did Denver replace Stapleton airport with Denver International while Chicago, Dallas and Houston (among others) kept their downtown airports open and busy in terms of their airport systems? Could individual case analysis shed some light in airport systems' "taxonomy" in order to help urban planners and decision-makers to conduct better decision-making in the future? Or are all these cases so local-specific that any such attempt to define this "taxonomy" becomes a rhapsody rather than a guide to best practices for urban and airport planners?

On an entirely different path, analyzing the case of busy central airports *versus* even busier newer and farther ones within the same metropolitan areas can be quite interesting in terms of urban planning challenges (e.g.: Shanghai's Hong Qiao *versus* Pudong, Seoul Gimpo *versus* Incheon, Kuala Lumpur Subang (Sultan Abdul Aziz Shah) *versus* Sepang (Kuala Lumpur International), Taipei Songshan *versus* Taoyuan, Bangkok's Don Mueang *versus* Suvarnabhumi, New York's La Guardia *versus* John F. Kennedy, and São Paulo's Congonhas *versus* Guarulhos airports – all listed on Table 2).

Finally, it should be highlighted that no tendency or trend curve adjusted well to the groupings' ratios dispersions (systematically low R^2 were found at all cases), although the replacement *versus* closed airports (blue dots in Figure 2 graph resulted maximum R^2 of 0.0968 for potency trend, quite similar to 0.0967 for exponential trend) shows a ratio of distance increase tendency that is visually more acceptable than that of the system forming *versus* original, central airports grouping (red dots in Figure 2 graph, which resulted R^2 of 0.0141 for logarithm trend and 0.0139 for linear adjustment).

Also, computing transport production values (number of million passengers per year multiplied by the distance in km) was checked but it did not provide any better type of statistical and/or mathematical correlation (R^2 ranging from 0.0022 to 0.0973, depending on the adjustment trend; no Figure shown).

6. CONCLUSIONS

Airports' distances from city centers increase as earlier original airports are replaced by newer ones, but not necessarily when new airports become operational for commercial aviation thus forming airport systems. The former situation shows an acceptable visual trend (despite not a good statistical correlation of any trend curve), while the latter situation shows widely spread data (the ratio of the two subgroupings do not show an apparent tendency of increase along time). On the other hand, when disregarding the ratio of distances and considering only the actual distances along time (purple *versus* green and red *versus* blue dots of Figure 1), the replacement and the system forming airports are clearly more distant from city centers than the closed and original central airports they respectively complement.

This is probably due to the fact that recent new airport systems are being formed by the mobilization of regional, smaller airports by LCC. While in many cases LCC operates in airports as far as 100 km away from the center of the cities they allegedly serve (such as Stockholm-Skavsta and Oslo-Torp airports), in some cases they do otherwise, triggering operations in older, more central, investment starved and less sophisticated airports such as Kiev-Zhuliany,

Milan-Linate, and Rome-Ciampino airports, all respectively more central than Kiev-Boryspil, Milan-Malpensa, and Rome-Fiumicino.

However intuitive it may be, not all cases of newer commercial airports compared to older ones imply increasing distances from city centers along time. The cases of airports being closed and replaced show such trend, while the cases of system forming and original, central airports not always do. This could justify further research and considerations on developing "taxonomy" of airport systems to shed lights of best practices for both urban and airport planners, as well as to decision-makers.

7. ACKNOWLEDGEMENTS

The author would like to thank the inputs provided by the peer reviewers, rendering a (hopefully) clearer and more consistent analysis, content and discussion. The responsibility for any remaining shortcomings and eventual mistakes is solely of the author.

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