HELIPAD CONNECTIVITY FOR ADVANCED AIR MOBILITY ON BIG CITIES IN THE STATE OF SÃO PAULO, BRAZIL

Peter Targino Klein*
Instituto Tecnológico de Aeronáutica (ITA)

Mauro Caetano de Souza
Instituto Tecnológico de Aeronáutica (ITA)

*** Corresponding author e-mail address**: peter.klein@ga.ita.br

PAPER ID: SIT2159

ABSTRACT

This study addresses the improvement of the helipads and airports of four urban centers to accommodate Vertiports for Advanced Air Mobility, which promises to mitigate the problems caused by accessibility hardships in the urban environment. Seeing as few studies embody the social aspect so profoundly in contrast to the technical aspect of the aircraft themselves, the helipads were mapped all around the state of São Paulo and the point distribution was submitted to K-means clustering to find the areas within the urban centers with more growth capacity and public utility. The main findings of this study reveal that specific goals of accessibility can be achieved with little action, but the overall gains in welfare are small without specific investments in new infrastructure.

Keywords: Aerodromes, Aeronautics infrastructure, Regional integration, Spatial occupation.

ACKNOWLEDGEMENTS

Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (Mestrado em Computação Quântica, Fotônica Integrada e Inteligência Artificial, Processo 405489/2022-6, e Produtividade em Pesquisa – PQ, Processo 304919/2022-5).

2. INTRODUCTION

As the up-to-date sustainability goals break down in four fronts: Environmental, Energetic, Economic and Social Equity; there has been a great tendency for big cities, still usually seen as car-philic and pedestrian-phobic, to shift towards the paradigm of Sustainable Mobility - urging city planners to innovate in urban mobility policies and bring more infrastructure to peripheral areas to improve their integration to the more economically prosperous city centers.

This study aims to analyze the possible ways the Local Aerial Networks (LANs) can be shaped with their Vertiport distribution in order to allow Advanced Air Mobility (AAM) to prosper in its role as an everyday means of transportation inside big cities. To achieve this, the following objectives were set:

- Propose configurations for the LANs in four urban centers in the state of São Paulo based on a set of criteria;
- Estimate how much more areas can be achieved in 15 minutes or under by including air transportation as an option alongside the other modals for each of the proposed LAN configurations;
- Evaluate and make judgment on whether it is more advantageous for overall accessibility to design LANs with a few robust Vertiports or to do so with smaller and more spreaded out ones.

3. LITERATURE REVIEW

Studies such as the one performed by Staricco (2022) lead to the belief that biggest challenges for municipal administrators will be about transportation and housing issues aligning with the goal of achieving 15-minute cities, where the inhabitants would be able to reach any kind of essential service establishments within a time window of 15 minutes after leaving their homes. However, the policies worldwide for zoning and land usage in most locations are still outrageously impeditive for this concept of accessibility, and make it so that concepts such as “smart cities”, “sustainable cities” and “15-min cities” end up becoming just a political slogan for public administrators, as the urban growth outpaces the supply of basic infrastructure in a vicious cycle phenomenon.

AAM powered by renewable energy and intelligent usage of resources in new city planning techniques is the key to boost the required innovation on urban mobility to achieve sustainability on the social and energetic aspects without sacrificing the environmental and the economic ones. Happ et al. (2017) proposes a shared economy of sensors for reducing operational costs and negative environmental impacts in the scope of Internet of Things (IoT), which could be applied to air traffic control of drones in passenger/cargo transportation - but such implementation would, of course, not be possible without a central entity with access to data from any aircraft utilizing the system, highlighting the first hardship of optimal resource utilization: right to secrecy and protectionism of private information/property.

As noted in Bachofner et al. (2022), operations in urban environments are currently very inefficient in the context of last-mile logistics, from both an economic and environmental perspective, making it a necessity to attain more sustainability in city logistics operations in general and in the passenger mobility industry in particular, to which AAM shines as an alternative in the pursuit of this goal, as long as the stakeholders collaborate with one another. Raj & Sah (2019) make the same case regarding stakeholder collaboration in air transportation, emphasizing the role of the government in the form of regulatory agencies as key players in ensuring the trust and safety of the public.

The Brazilian *National Agency for Civil Aviation* (ANAC) is still figuring out how to deal with the imminent debut of widespread usage of electrical Vertical Take-off and Landing (eVTOL) aircraft for Urban Mobility, but perhaps the platform proposed by Happ et al. (2017) becomes a good guide for it, with the agency itself centralizing the flight data and forcing the stakeholder collaboration for AAM operations. The intern reorganization of the agency and the capability to maintain its newfounded data centers for AAM could be a deterrent in the sense of becoming another choking point in which the refusal to invest in long term system optimality would turn out to further bring Social Exclusion instead of Social Equity, as the air traffic management capacity wouldn’t grow at the same rate of the demand for air transportation.

Rajendran & Srinivas (2020) show the same concern regarding sustainability, calling out the energy, health and time losses in ground transportation modes as evidence for the need of exploration of faster alternatives for passengers in their everyday commute within urban areas, claiming that road congestion could be alleviated, Pukhova et al. (2021), however, concluded that the time savings obtained with intraurban air mobility are negligible in the case of operations involving flying taxis being chosen over conventional ground transportation, including both traditional helicopters and newer eVTOL aircraft - making the case for air mobility as a viable option for rural areas instead, such as mountainous regions that would require roads to stretch for longer distances in order to traverse around the disfavorable topography or to pass by the natural obstacles through the construction of expensive tunnels or bridges, whose maintenance can usually be very costly as well.

4. METHODOLOGY

In order to achieve the general objectives exposed, the following specific objectives are to be pursued in order for each of the four urban centers chosen:

- Every helipad in the state of São Paulo is mapped based on registration in ANAC;
- The helipads are grouped in clusters according to location and relative distance to the other nearest clusters;
- The major, hub-like Vertiports of the urban centers are allocated on already existing airports;
- A skeleton for the different LANs is then molded by pinpointing approximate locations for the Vertiports that will compose them in different restrictive conditions;
- To finally achieve an unique LAN, it is analyzed which helipads would offer a greater public utility as Vertiports and are close to the approximate pinpointed locations of the skeleton;
- Vertiports now compose a unique LAN by having their approximate locations in the LAN skeleton being updated into the chosen helipads precise locations;
- Travel times are measured and compared to essential service-providers utilizing intraurban air transportation versus not using it;
- The proportion of the population that can be well served in the LANs gets estimated;

In order to better conduct the present study, a few technical points are to not be addressed, as they could bring too much complexity for the early stage evaluations intended. That being said, the four assumptions made in order to simplify the analysis henceforth made are:

1. A clear definition of the necessary components each infrastructure would require in the initial phase of upgrades into Vertiports is already known and immediately applicable;
2. Any airport can begin operating as a hub-like Vertiport, with no loss in operation efficiency for the air operations they already host before the usage of eVTOL aircraft;
3. Every no-flight zone has been identified and any pair of Origin-Destination (OD) points on the same LAN have a possible and well-defined aerial route connecting them, whether it is a direct route or not;
4. Great São Paulo is the only of the four LANs where it is considered viable to have some new infrastructure developed specifically as a Vertiport for AAM, considering how much of a disparity it has in comparison to everywhere else regarding air transportation.

In terms of AAM infrastructure, existing helipads can be upgraded into Vertiports to serve as connectivity points for aerial networks, as it has been proposed in a number of studies such as the one performed by Ribeiro et al. (2023), which considers the Congonhas Airport, inside São Paulo Capital City, as a hub of operations for intraurban air transportation. The general idea of these studies is that such undertaking would facilitate the use of eVTOL vehicles for public air transportation, as it would better connect the already existing infrastructure and reduce the high initial costs that could prompt hesitation in early investments.

Taking that into account, alongside the remarks and conclusions made by Pukhova et al. (2021) and Rajendran & Srinivas (2020), it is

possible to better integrate the central areas in major urban centers in the state São Paulo to their peripheral areas, as it is to use the same modal to the mountainous rural areas near said urban centers.

The data for the usage of other Public Transportation Methods were also gathered in the corresponding municipal administrations' websites and the São Paulo state's *Empresa Metropolitana de Transportes Urbanos de São Paulo* (EMTU) for estimation of demand in said cities and expansion plannings to their neighbor towns, leading to a few cities being chosen to be centers of innovation for eVTOL-based Public Air Transportation.

The 585 helipads registered in the state of São Paulo were divided in 32 clusters based on the K-means clustering algorithms described in Ikotun et al. (2023). Table 1 is shown following-up relevant data for the four major urban centers considered, centered around the cities of Campinas, São José dos Campos, São Paulo Capital City and Sorocaba.

Although the same kind of analysis and propositions can be made for other urban centers in the state of São Paulo, such as in the Santos Bay Area or in the Northern Litoral, these locations are of interest much more in the sense of a dedicated interurban air transportation study, as they are dense touristic destinations that would clearly very much benefit from innovations regarding accessibility from other urban centers towards them, but not as much in the context of intraurban air transportation from an end of the city to the other, as essential services are more spread out over them.

Table 1. Data on major cities in the state of São Paulo, Brazil and their great areas.

(Great) City	*Population*	*GDP (times R$ 1000)*	*Number of Helipads*
Campinas	1,138,309	61,397,263	24
Great Campinas	3,791,440	267,795,559	59
São José dos Campos	697,428	39,697,501	8
Great São José dos Campos	1,717,563	86,570,552	33
São Paulo	11,451,245	714,683,362	194
Great São Paulo	20,693,254	1,179,418,193	295
Sorocaba	723,574	35,015,188	7
Great Sorocaba	1,786,332	77,402,548	39
4 Great Urban Areas combined	27,988,589	1,611,186,852	426

5. RESULTS

The helipad distribution in the region of interest can be seen in Figure 1 below, where 20 of the initial 32 clusters were differentiated by color of points in the map, followed by Table 2, which regards data on the 13 clusters closer to the Congonhas Airport by the K-means division:

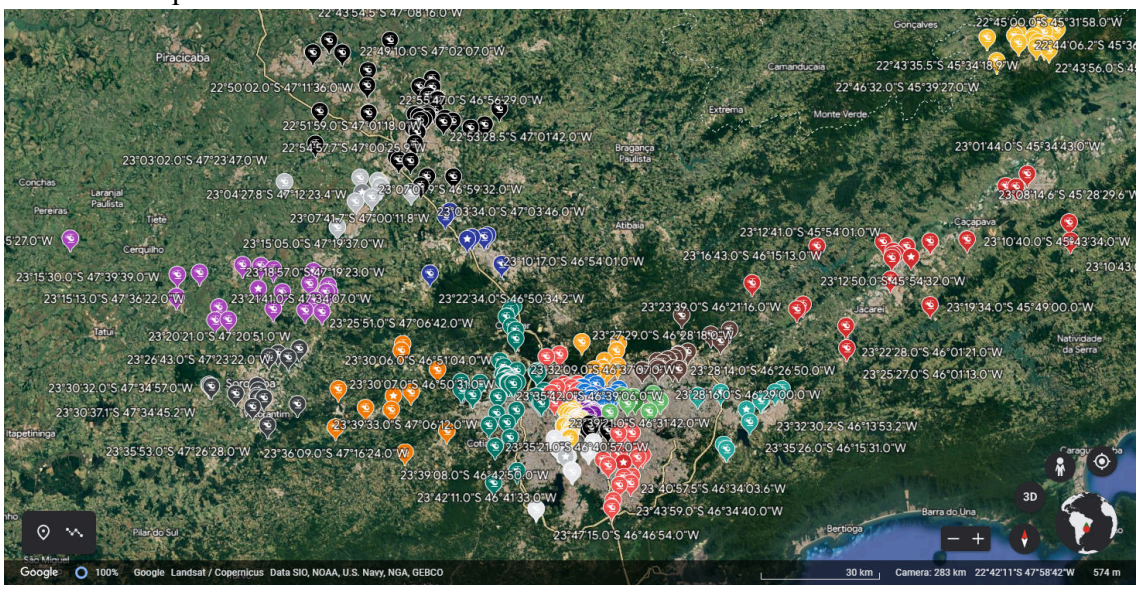


Figure 1 Distribution of helipads where point colors differentiate neighboring clusters filtered to the region of interest. Source: Own Research.

Table 2. Location and size of 13 clusters closer to Congonhas Airport seen in Figure 1 .

Cluster ID	*Central Coordinates*	*Avrg. distance point-center*	*Number of Helipads*
5	23°33'45.9"S 46°15'59.2"W	8.0 km	9
6	23°26'17.9"S 46°25'58.3"W	6.1 km	15
13	23°30'13.7"S 46°51'04.3"W	5.5 km	54
14	23°10'48.4"S 46°57'00.0"W	7.2 km	7
19	23°40'57.5"S 46°34'03.6"W	6.0 km	16
24	23°35'43.6"S 46°41'27.6"W	1.7 km	94
25	23°31'41.4"S 46°38'02.1"W	3.2 km	21
26	23°33'46.5"S 46°39'15.5"W	0.8 km	34
27	23°32'41.9"S 46°32'21.0"W	3.9 km	8
28	23°30'22.1"S 46°42'50.0"W	3.8 km	11
29	23°27'12.9"S 46°36'53.1"W	4.0 km	8
30	23°40'10.2"S 46°42'33.4"W	3.9 km	12
31	23°36'05.0"S 46°38'22.8"W	1.9 km	6

The short average distance of the points to their respective cluster centers, alongside the high amount of clusters close together make it noticeable how dense the Great São Paulo urban center is in terms of air transportation infrastructure in the form of helipads, especially when compared to the more spreaded out clusters around the other urban centers analyzed, as can be seen ahead in Table 3, but also calls attention to the Social Exclusion aspect of the air transportation frame when the two most eye-catching clusters are so close to each other and in an area between two airports, those being cluster 24 (centered near *Instituto Butantã*) with the highest amount of helipads and cluster 26 (centered in *Avenida Paulista*) with the shortest average distance to the cluster central point.

Table 3. Location and size of the 7 remaining clusters seen in Figure 1 .

Cluster ID	*Central Coordinates*	*Avrg. distance point-center*	*Number of Helipads*
4	23°13'05.3"S 45°51'48.9"W	20.3 km	21
7	22°53'58.3"S 47°04'38.8"W	10.0 km	40
11	23°31'56.0"S 47°07'52.2"W	11.4 km	10
12	23°30'31.6"S 47°27'59.3"W	8.0 km	15
15	23°17'26.5"S 47°27'43.5"W	14.8 km	20
16	23°04'27.8"S 47°12'23.4"W	7.4 km	9
23	22°43'35.5"S 45°34'18.9"W	4.6 km	16

Hence, in the Great São Paulo, the Congonhas Airport and Campo de Marte Airport can begin as the spine that will be shaping the skeleton of the Great São Paulo LAN centered around the most intense areas near clusters 24 and 26, as Figure 2 below shows. The Figure 3 that follows it contains the skeleton that comes after the air connecting attempt that immediately succeeds.

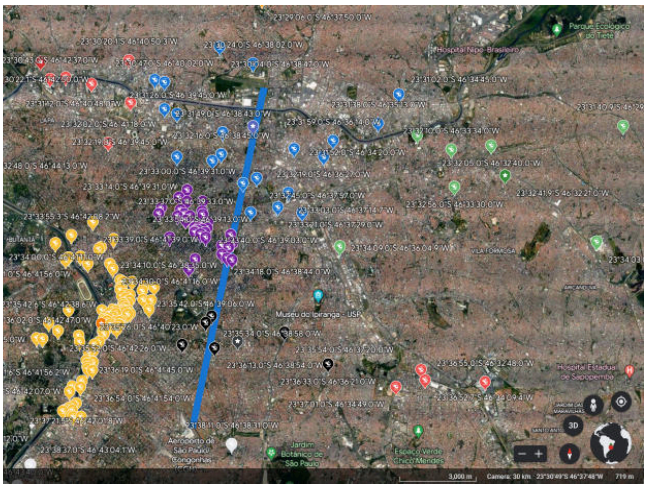


Figure 2 The line that connects Congonhas Airport and Campo de Marte Airport is traced and can act as the spine of the skeleton of Great São Paulo LAN. Source: Own Research.

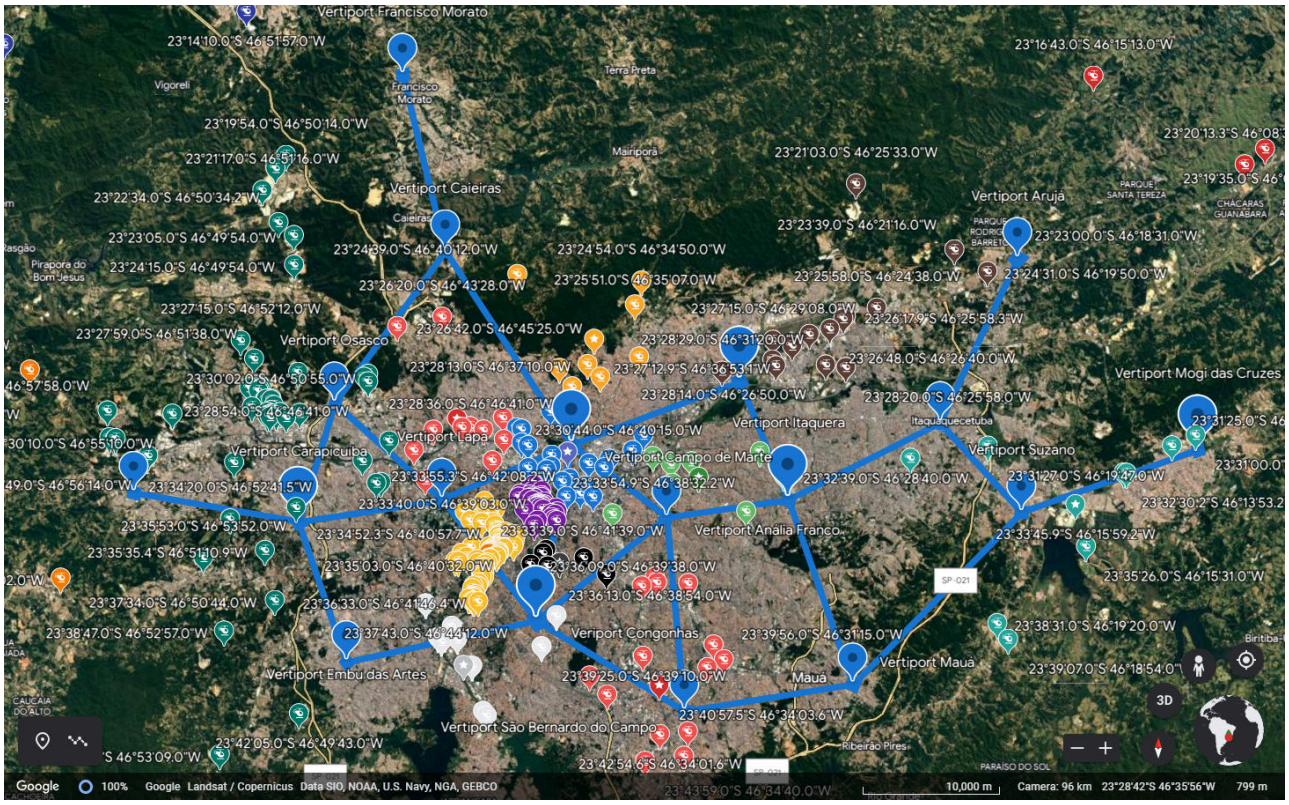


Figure 3 Skeleton of the Great São Paulo LAN in dark blue overlaid with the helipad locations. Source: Own Research.

Similarly, Great Sorocaba can have its LANs' skeleton molded taking the Sorocaba Airport as a debuting point, resulting in the skeleton shown in Figure 4 below:

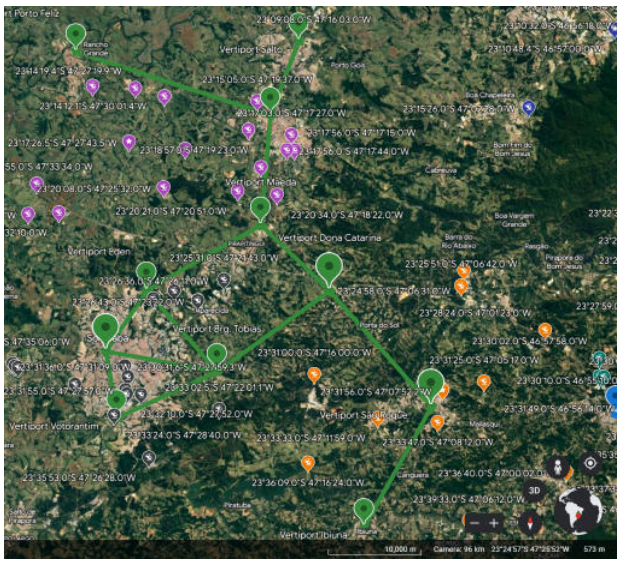


Figure 4 Skeleton of the Great Sorocaba LAN in green overlaid with the helipad locations. Source: Own Research.

When in comes to the Great Campinas, although official political divisions make them separate, its peripheral towns begin to mix much more with the neighboring regions and make it sort of a gray area whether the intraurban integration should extend towards locations such as Indaiatuba and Jundiaí or leave them to Great Sorocaba and Great São Paulo respectively. In order to assert Campinas as a regional force, both towns were included in Great Campinas LAN skeleton, as shown in Figure 5 below:



Figure 5 Skeleton of the Great Campinas LAN in brown overlaid with the helipad locations. Source: Own Research.

The Great São José dos Campos region is a very distinct case from the other 3 urban centers since it is located along a valley and, as

expected, the urban growth followed the low altitudes, while a few locations on the mountainous hills got to become big as touristic destinations.

That makes it so the LAN skeleton becomes very linear - not only that, but it goes along very closely to the biggest highway in the valley, the SP-060 Highway - towards Campos do Jordão and its 16 helipads with only a small detour, as shown in the Figure 6 ahead.

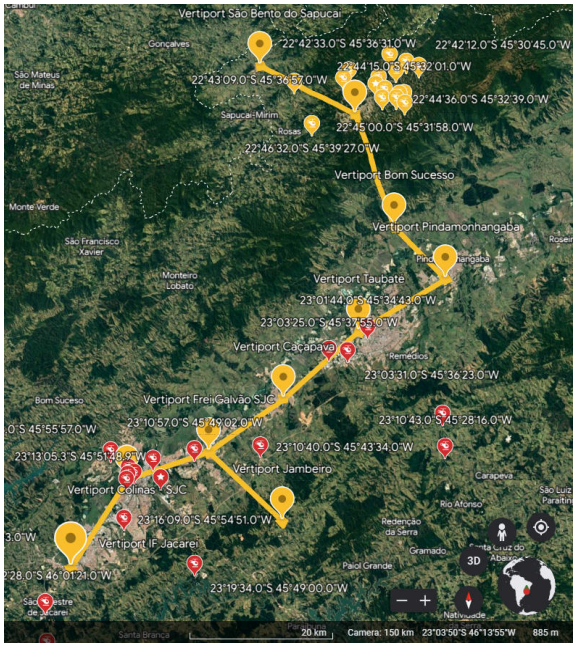


Figure 6 Skeleton of the Great São José dos Campos LAN in yellow overlaid with the helipad locations. Source: Own Research.

With the 4 skeletons of the LANs defined, the possibilities are tested and the notorious ones are proposed as shown in Figures 7 through 10, where each urban center is shown with the skeleton being overlaid by the actual locations of the already existing helipads that are proposed to be upgraded into Vertiports:

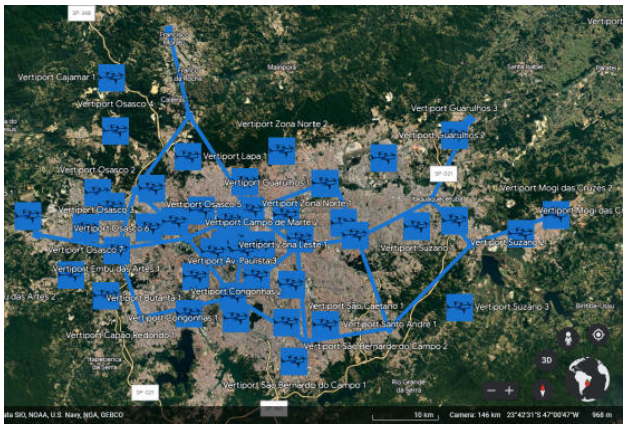


Figure 7 Vertiport locations for the LAN of Great São Paulo using the already present helipads and airports.

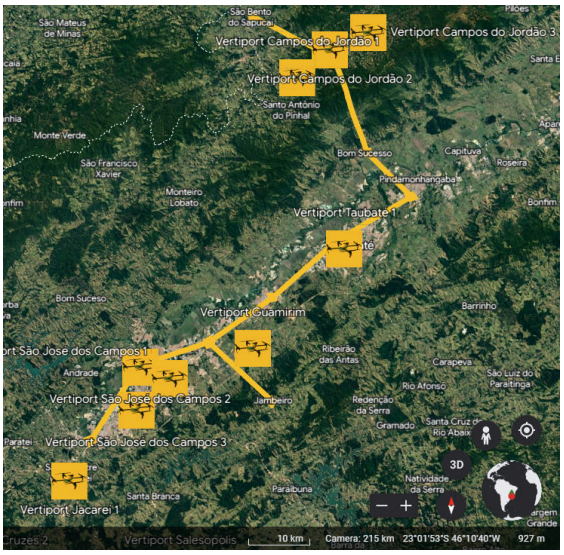


Figure 8 Vertiport locations for the LAN of Great São José dos Campos using the already present helipads and airports.

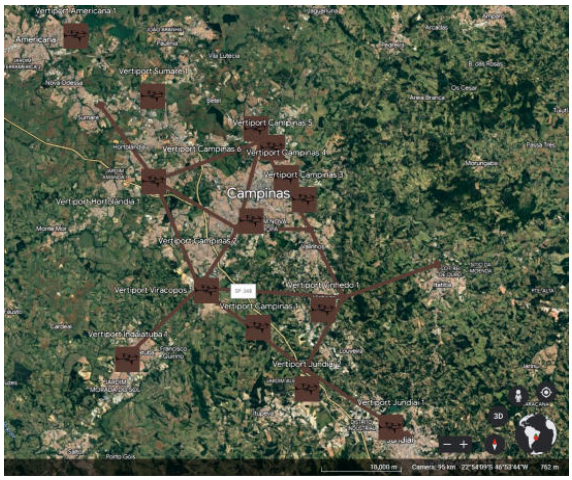


Figure 9 Vertiport locations for the LAN of Great Campinas using the already present helipads and airports.

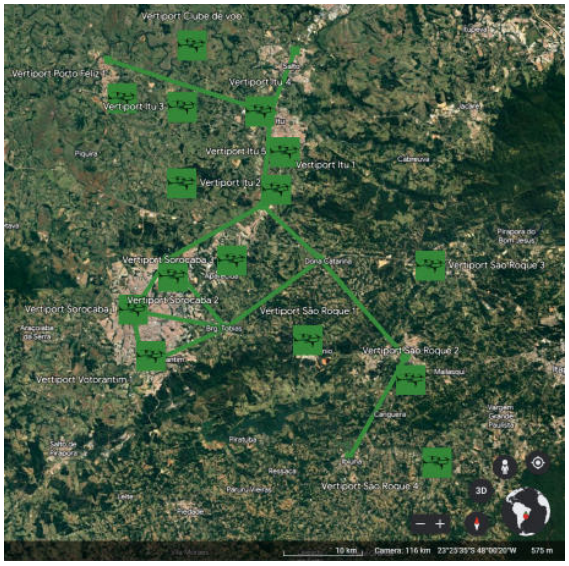


Figure 10 Vertiport locations for the LAN of Great Sorocaba using the already present helipads and airports.

Regarding the accessibility to essential services, the inhabitants of peripheral areas can expect to travel to hospitals, establishments of local authorities (*Poupatempo*, police battalions etc.) and big employment locations such as factories within a 15-minute time window with considerable ease, but only for specific destinations. As an example, *Colinas Shopping* in São José dos Campos can be accessed in just under 8 minutes by a local in the southern zone of the city - which would usually require about 45 minutes by public bus, but that is the only OD pair that actually becomes advantageous in the entire Great São José dos Campos.

However, the other 3 urban centers all show multiple OD pairs with good improvements in accessibility.

In the case of Great Campinas, such good outcome comes majoritarily by the Vertiports in 22°56'23.0"S 47°04'15.0"W and 22°51'28.0"S 47°02'42.0"W, which are two concentrations of economic activity, housing and near big avenues.

In the case of Great Sorocaba, the positive outcome involves mostly the proximity of Sorocaba and Itu, giving so many more easy options for the people who live between them, particularly in Aparecida (near Vertiport 23°26'43.0"S 47°23'22.0"W) - which can access central Sorocaba in 12 minutes instead of 30 minutes and access central Itu in 10 minutes instead of 25 minutes.

In the case of Great São Paulo, the busy areas on the western side of the city and into neighboring town of Osasco will see a boom in activity, where Osasco residents will be able to reach *Avenida Paulista* in about 12 to 15 minutes as opposed to the outrageous previous times of 60 to 80 minutes. Big São Paulo neighborhoods such as Itaquera, Vila Formosa and Anália Franco, alongside the towns of São Caetano do Sul and Mauá will still be very marginalized though, as no measurable gain will be obtained without the development of specific infrastructure for intraurban air transportation in these locations.

6. CONCLUSION

Of course, not all areas are well served with helipads, such as Brigadeiro Tobias and Dona Catarina in Great Sorocaba, Mauá and Santo André in Great São Paulo, Caçapava and Pindamonhangaba in Great São José dos Campos, Valinhos and Sumaré in Great Campinas. Nonetheless, having many Vertiports available also isn't enough, as even the Vertiports proposed in Campos do Jordão are on locations with low traffic and more close to touristic points than to essential services (which isn't a bad thing, it just doesn't serve the purpose of the study).

Not only that, but it becomes clear that interurban flights with eVTOL aircraft will be helpful immediately for the general public, as there is much travel time to be saved traversing the mountainous topography all around the biggest urban center in Brazil - the São Paulo Capital City metropolitan area - in a matter of interurban logistics, another pillar of AAM that the present study did not delve into.

It is noticeable that the pair Campinas - São Paulo is particularly costly for ground-based traveling, while the urban center of São José dos Campos can hardly grow in the South East - North West direction due to the steepness of the land. These observations suggest more feasibility of leveraging existing infrastructure for public interurban air transportation, instead of intraurban - which aligns with the conclusion of Pukhova et al. (2021).

Overall, the implications of this study greatly contribute to the efficacy of Advanced Air Mobility in promoting innovative air transportation solutions in Brazilian cities through AAM by bringing awareness to the necessity of having well-established objectives to ensure action is taken without hastiness.

7. REFERENCES

ANAC. (2023, Mai 2). *Agência Nacional de Aviação Civil. Lista de aeródromos civis cadastrados*. Retrieved Mai 2, 2023, from https://www.gov.br/anac/pt-br/assuntos/regulados/aerodromos/lista-de-aerodromos-civis-cadastrados

Bachofner, M., Lemardelé, C., Estrada, M., Pagès, L.: City logistics: Challenges and opportunities for technology providers. **Journal of Urban Mobility**. v. 2, 2022. 10.1016/j.urbmob.2022.100020.

Happ, D., Karowski, N., Menzel, T., Watteyne, T., & Wolisz, A.: Enabling Cloud-Centric IoT with Publish/ Subscribe Systems. (2017). Ch. 10 in

Internet of Things: Challenges, Advances, and Applications. **CRC Press**. 10.1201/9781315155005-10.

IBGE. (2023, Jun 28). *Instituto Brasileiro de Geografia e Estatística. Censo 2022*. Retrieved Sep 2, 2023, from https://censo2022.ibge.gov.br/panorama/

Ikotun, A. M., Ezugwu, A. E., Abualigah, L., Abuhaija, B., Heming, J.: K-means clustering algorithms: A comprehensive review, variants analysis, and advances in the era of big data, **Information Sciences**. v. 622, pp. 178-210, 2023. 10.1016/j.ins.2022.11.139.

Pukhova, A., Llorca, C., Moreno, A., Staves, C., Zhang, Q., Moeckel, R.: Flying taxis revived: Can Urban air mobility reduce road congestion?. **Journal of Urban Mobility**. v. 1, 2021. 10.1016/j.urbmob.2021.100002.

Raj, A. & Sah, B.: Analyzing critical success factors for implementation of drones in the logistics sector using grey-DEMATEL based approach, **Computers & Industrial Engineering**. v. 138, 2019. 10.1016/j.cie.2019.106118.

Rajendran, S. & Srinivas, S.: Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. **Transportation Research Part E: Logistics and Transportation Review**. v. 143, 2020. 10.1016/j.tre.2020.102090.

Ribeiro, J. K., Borille, G., Caetano, M., Silva, E. J.: Repurposing urban air mobility infrastructure for sustainable transportation in metropolitan cities: A case study of vertiports in São Paulo, Brazil. **Sustainable Cities and Society**. v. 98, 2023. 10.1016/j.scs.2023.104797.

Staricco, L.: 15-, 10- or 5-minute city? A focus on accessibility to services in Turin, Italy. **Journal of Urban Mobility**. v. 2, 2022. 10.1016/j.urbmob.2022.100030.