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REVISTA BRASILEIRA DE GESTÃO E DESENVOLVIMENTO REGIONAL
V.21, N°1, Jan-Abr/2025 | Taubaté/SP - Brasil | ISSN 1809-239x

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Ricardo Fernandes Consulin[1] | Maurício Oliveira de Andrade[2]

Received: 10/14/2022
Accepted: 08/06/2025

[1] Master's degree in Civil Engineering (UFPE).
Email: ricardoconsulin@yahoo.com.br

[2] PhD in Civil Engineering (UFPE).
Professor at the Federal University of Pernambuco.
Recife, PE, Brazil.
Email: mauricio.andrade@ufpe.br

ABSTRACT

The air transport market, which is extremely competitive, faces constant economic difficulties. In this challenging environment, any success in finding promising new markets to start operating local airports (spokes) or improving the operation of existing ones becomes a differentiator that can impact the economic performance of airlines. In addition, identifying potential cities for operating these air routes provides information that can be used by all players in the aviation sector, whether planners, operators, managers, public officials, or administrators, with a view to increasing the efficiency of air network management and assisting in the development of public policies. Thus, the objective of this study is to identify the factors that increase the probability of a small airport or local airport, which is not classified as a hub by the National Air Plan, to operate flights, using a binary logit model. The most significant variables that appeared, considering Brazil and each of its regions, were: population, airport aeronautical unit (UAA), and runway length. The predictability of the model in all regions of the country was greater than 61% for aerodromes with air operations and greater than 69% for those without. The North region had the highest probability of local airports to operate flights, while the Southeast region had the lowest probability.

Keywords: Air network. Spoke airports. Logit model. Air transport.

RESUMO

O mercado de transporte aéreo, que é extremamente competitivo, enfrenta dificuldades econômicas constantes. Nesse ambiente desafiador, qualquer sucesso na busca de novos mercados promissores para iniciar a operação de aeródromos locais (*spokes*), ou para melhorar a operação dos existentes, torna-se um diferencial que poderá impactar na performance econômica das companhias aéreas. Além disso, a identificação de cidades potenciais para a operação dessas rotas aéreas traz informações que podem ser utilizadas por todos os *players* do setor aéreo, sejam planejadores, operadores, gerentes, agentes públicos ou administradores, visando aumentar a eficiência do gerenciamento da malha aérea e auxiliar na elaboração de políticas públicas de desenvolvimento. Assim, o objetivo deste trabalho é identificar os fatores que aumentam a probabilidade de um pequeno aeroporto ou aeroporto local, que não é classificado como *hub* pelo Plano Aéreo Nacional, operar voos, utilizando um modelo *logit* binário. As variáveis significativas que mais apareceram, considerando o Brasil e cada uma das suas regiões, foram: população, unidade aeronáutica de aeroporto (UAA) e comprimento de pista. A previsibilidade do modelo em todas as regiões do país foi superior a 61% para aeródromos com operação aérea e superior a 69% para os que não a tinham. A região Norte apresentou as maiores chances de que aeródromos de porte local operassem voos enquanto a região Sudeste teve a menor probabilidade.

Palavras-chave: Malha aérea. Aeroportos *spokes*. Modelo *logit.* Transporte aéreo.

INTRODUCTION

The Covid-19 epidemic had a major impact on the global air transport sector. Since the sharp decline in the number of passenger beginning in March 2020, when the World Health Organization (WHO) declared it a pandemic, the sector has recovered slowly, with cargo transport less affected than passenger transport. In this regard, several studies indicate that domestic flights have recovered more quickly than international flights, as, in addition to the implementation of measures being more agile and less complex, fares are cheaper and flight times are shorter. (Czerny et al., 2021; Sun; Wandelt; Zhang, 2020).

As such, several measures to stimulate the resumption of flights have been developed, including the improvement of self-service check-in services, the creation of advertising campaigns to encourage consumers to fly again, discounts on ticket prices, the restructuring of the airline network with the optimization of supply and demand, the search for new potential markets to be explored, as well as numerous other initiatives that seek to maintain the financial health of the business through continuous efficiency improvements.

In this search for unexplored niches, it is well known that an airport with regular air routes is not only a good indicator of a region's economic strength, but also a driver of local economic development. Thus, when a new air route is established in a given city, new business opportunities arise, more jobs are created, more taxes are collected, and an entire value chain is established. In addition, inclusion in the national air network increases the efficiency of travel and creates opportunities.

It should be noted that the literature is rich in studies on the creation and/or reactivation of air routes, in which models are explored to explain the reasons for these activations. However, the phenomenon has not been studied in relation to the type of airport that receives the new route.

Exploring this gap, an exploratory analysis was conducted on data from the National Civil Aviation Agency (ANAC) between 2020 and 2024, seeking to identify the factors that increase the likelihood of a small airport or local airport (spoke) not classified as a hub by the National Aviation Plan to operate regular flights.

The study proposes to test the hypothesis that these spoke airports have other common factors that contribute to the potential establishment of an air link, in addition to demand and profitability issues. To this end, binary logit models were tested for each region of the country and then for Brazil as a whole to discover significant variables that explain the probability of an operation occurring at an aerodrome that is not a hub.

The article is structured into five sections in addition to this introduction. Section two reviews the literature on the opening of new air routes, while section three discusses the methodology used. Section four discusses and analyzes the results, concluding in section five with highlights of the main points found, limitations, and recommendations for future work.

AIRPORTS, ECONOMIC DEVELOPMENT, AND AIR ROUTES

The economy and the development of society have always been linked to transportation, as they cannot happen without a supporting infrastructure. When there is an efficient transportation system, socio-economic opportunities and benefits are generated, which in turn generate positive multiplier effects. The exchange of goods and services has been occurring since ancient times, and five major waves of economic development can be identified, each supported by a new transportation technology (Rodrigue, 2020): i) seaports (16th to 18th centuries) that sustained the navigation and trade of colonial empires; ii) rivers and canals to support trade within North America and Western Europe (late 18th and early 19th centuries); iii) railways (19th century) linked to the second stage of the industrial revolution; iv) highways (20th century), mainly after World War II; and finally, v) airways and information technology (second half of the 20th century), with improved logistics development and accelerated mobility of passengers, cargo, and their associated information flows.

Air transport was initially an elitist mode of transport with expensive tickets that were inaccessible to most of the population. This began to change after the deregulation of the market in several countries (USA, 1978; Europe, peak in 1997; Brazil, 1990s), leading to the rapid expansion of the airline network.

According to Rodrigue (2020), air traffic is correlated with per capita income, but the relationship is interdependent. He also notes that the economic impact of air transport is most strongly felt near air hubs, but the catalytic effect of air accessibility extends throughout the economy, with entire sectors heavily dependent on it: logistics, consulting, advertising, and tourism, for which air accessibility is vital.

It was observed that in the development of the National Aviation Plan – PAN (2024, p.78) that the increase in demand for air transport was related to economic aspects of population and income growth, as well as the time required to access the airport, which are consequently essential factors for identifying promising cities in terms of implementing new air routes.

The literature is rich in discussions about the causality between economic development and air transport, with no consensus on whether the relationship is unidirectional (Fernandes; Pacheco, 2010; Hakim; Merkert, 2016) or bidirectional (Hanson et al., 2022; Hu et al., 2015; Marazzo; Scherre; Fernandes, 2010).

Regardless of this, it is recognized that the relationship between economic development and air traffic is stronger in terms of influencing air activity, i.e., in cities where the economy is more vibrant, it is more likely to find aerodromes that may or may not be operational, as this would depend on other factors.

A good market for the operation of spoke-type aerodromes would be small (<100,000 inhabitants) and medium-sized (between 100,000 and 500,000 inhabitants) cities, according to the classification given by the IBGE, in which some type of economic activity stands out, such as in municipalities where agribusiness is well developed (e.g., Barra do Garças – MT, Lábrea – Amazonas, Sorriso – MT, Vacaria – RS, Varginha - MG), or with mineral extraction activity (e.g., Coari – AM), or livestock (e.g., Porto de Moz – Pará, Santa Rosa - RS), or industry (Apucarana – PR, Franca – SP) or tourism (e.g., Bonito - MS, Itanhaém – SP, Cruz - CE), or areas with universities (e.g., São Carlos – SP; Serra Talhada - PE), etc.

Medium-sized cities are a connecting element in the urban network between large cities on one side and small towns and rural areas on the other. Due to their central location, they act as structuring elements in the region where they are located, reducing regional disparities, mediating urban flows, creating opportunities, and improving the quality of life of their inhabitants (Amorim Filho; Serra, 2001; Jardim; Silveira, 2020). Thus, medium-sized or small cities with populations close to 100,000 inhabitants become potential markets for future spoke-type airport operations.

The activation of these routes in these smaller cities will not only bring immediate economic benefits, such as attracting public and private investment, creating jobs, increased tax revenue, and higher GDP per capita, among other benefits. It will also promote citizenship by allowing the population to connect to the national air network, reducing travel time compared to road/water transport, improving access to health services in other cities, and creating educational opportunities and more efficient professional exchanges.

The first step for aerodromes to receive flights is that they are registered and in good standing with ANAC, with all physical and operational characteristics reported, and in minimum operating conditions for runways, aprons, and, eventually, passenger terminals with safety, with the infrastructure receiving a designation.

With the aerodrome operational, the administrator begins to work on finding airlines to implement flights, as well as operators seeking aerodromes that are favorable both from a profitability standpoint and strategically for accessing new markets. For more established aerodromes, the market itself adjusts passenger and cargo supply and demand. However, for new markets, some factors for verifying potential demand need to be analyzed.

Several authors identify two factors that affect demand: geoeconomic factors and those related to services (Albayrak et al., 2020; Das; Bardhan; Fageda, 2022; Jorge-Calderón, 1997; Kanafani, 1983; Rengaraju; Arasan, 1992).

In relation to services, aspects such as aircraft type, fares, frequency of operations, departure times, among others, are analyzed. Meanwhile, with regard to geoeconomic factors, information on population, income, GDP, GDP per capita, economically active population, HDI, trade, tourism, level of education, unemployment rate, distance between cities, airport catchment area, distance to a major city, travel time ratio (air/land), and intermodal competition are taken into account.

Some authors highlight other variables that may also influence demand: day of the week, season, customer loyalty, mileage programs, flight comfort, flight delays, low-cost carriers (LCCs), results from the trade and services sector, degree of connectivity between two cities, availability of aircraft with sizes compatible with existing demands, etc. (Chin, 2002; De Dios Ortúzar; Simonetti, 2008; Lohmann; Vianna, 2016; Mason, 2005; Olischer; Dörrenbächer, 2013; Tretheway; Oum, 1992; Zhang et al., 2016).

Some routes can be created based on government tax breaks to attract more flights, lower fares, improve accessibility, or promote economic and tourism development in a region, such as the agreements signed between airlines and some Brazilian states, such as Rio Grande do Sul in 2019 and Amazonas in 2021. This form of incentive also appears in other countries, as explored in the works of several authors (Allroggen; Malina; Lenz, 2013; Lohmann; Vianna, 2016; Kinene et al., 2020; Zhang et al., 2016).

Normally, opening new routes involves expanding the airline network, which in Brazil is hub-and-spoke, with a few airports concentrating most of the passenger and cargo traffic. Guarulhos International Airport (SBGR) in São Paulo, which is the largest in the country, accounted for approximately 19.4% of all passengers transported, 15.8% of the number of landings and takeoffs, and 35.6% of the country's total cargo transport between 2019 and 2024 (BRAZIL, 2025).

However, for a continent-sized country, better distribution of aviation sector assets and effective management of available investment resources are key strategic decisions. Based on these considerations, the National Aviation Plan (PAN) 2018-2038 was conceived and formulated in accordance with the country's National Transport Policy, which was later revised and updated to the PAN 2024, covering the period 2022 to 2052.

The PAN (2018) presents nine sectoral objectives, four of which are directly related to the air network: accessibility, connectivity, efficiency, and development. All planning actions are based on a survey conducted in 2015 by the Planning and Logistics Company (EPL) at 65 Brazilian airports. The results showed that 84% of airport demand was located in urban agglomerations in the immediate vicinity of the existing infrastructure. Based on this information, 772 Territorial Planning Units (UTP) were created, which served as the basis for the construction of an origin-destination matrix for air transport.

Based on this zoning, two classifications were created for aerodromes, as shown in Table 1: one by function in the network and the other by size of operation; the latter to support infrastructure needs, which was the classification used in this article; the former to consider the potential gain for the sector's objectives.

Table 1 | Airport Classification

By network function		By size	
Metropolitan		**Hub**	
Primary	16	Large	20
Regional capital	12	Medium	18
Complementary	22	Small	29
Regional		Local	508
Primary	84	Latent	122
Secondary	55		
Complementary	508		
	697		697

Source: PAN (2018)

In the classification by size, the PAN (2018) used the concept of Aeronautical Airport Unit (UAA). The UAA considers the number of passengers processed (boarding and disembarking) with a weight of 1 and the number of aircraft movements (landings and takeoffs) with a weight of 4. Next, all UAAs are normalized and a Reference UAA – UAA% is created for each airport, which allows it to be classified as a large hub (UAA > 1%), medium hub (UAA > 0.25%), small hub (UAA > 0.05%), local (UAA > 0%) or latent (airfields with no recorded movement).

Similar classifications can be found in the literature for studying network structure, growth capacity, and route hierarchies, as presented in Huber's work (2016), in which he divides 164 Chinese airports into four types: five type 1 hubs, six type 2 hubs, 129 spokes, and 24 sub-spokes, according to traffic volume, number of airlines, and the nature of the airports to which they are connected. He treats a spoke airport as directly connected to the hubs and the sub-spoke class as connected to the spokes or other sub-spokes.

As can be seen, approximately 78.7% of the aforementioned spoke airports, the local aerodromes covered by this study, within the classification by size, represent 79.9% of the aviation sector's infrastructure and are an excellent asset to be exploited by the Union and private initiative, in favor of the development and expansion of the national air network, which in May 2025 had 136 (one hundred and thirty-six) destinations with regular flights (ANAC, 2025). For comparison purposes, Das, Bardhan, and Fageda (2022) report 189 (one hundred and eighty-nine) airports operating in India, and Zhang et al. (2017) report 216 (two hundred and sixteen) in China in 2016, with a forecast of 370 (three hundred and seventy) by the end of 2025.

Thus, after a brief theoretical discussion, covering the causality of the relationship between economic development and air transport, the opening of air routes, and subsequently the presentation of airport classifications made by PAN (2018), Brazil's spoke airports and their potential to be explored will be analyzed using the proposed methodology, which will be discussed below.

METHODOLOGY

The theoretical basis highlighted that the causal relationship between economic development and air transport, although not a consensus in academia, sparks curiosity about how it could work between small and medium-sized cities and local airports. The prospects for successfully establishing regular air routes in those cities with dynamic economies, for interconnection in the national air network, could be studied. For this investigation, in addition to the populations, whether or not there are aerodromes in the cities, and whether or not there are regular routes, it is necessary to know what is contained in the National Air Plan for each region.

Thus, to achieve the objective proposed by this article, which is to identify the factors that increase the probability of a small airport or local airport that is not classified as a hub by PAN (2018) to operate, information on flights between 2020 and 2024 (until December).

The data was collected from the agency's website and refers to regular and non-regular domestic flights operated by Azul, Gol, and Latam in 2020: 13,500 of the 26,900 existing data points; in 2021: 14,600 of the 28,700 existing data points; in 2022: 18,700 of the 35,800 existing data points; in 2023: 19,400 of the 39,100 existing data points; and in 2024: 19,500 of the 40,300 existing data points.

Data on aerodrome characteristics were also collected from the same website, according to the list of public aerodromes dated July 1, 2025, which contained information on designation, location (city, geographical coordinates), physical characteristics of the runways (length, width, surface strength, type of pavement, and altitude), type of aerodrome operation (daytime, nighttime), and status (registered or closed).

Information regarding socioeconomic and demographic aspects was obtained from the IBGE website, and tourism information was obtained from the Ministry of Tourism - Map of Tourism in Brazil.

Data on aerodrome classification by size (hub – UAA% > 0.05, local – UAA% > 0, or latent) were obtained from the plans contained in the PAN (2018) and Appendix XI of the PAN (2024), in which aerodromes that were not located in cities with hubs, that were not closed, deactivated, or unregistered, and that had the following minimum physical characteristics were separated: concrete or asphalt pavement, minimum length and width of 1,000 m x 23 m, and pavement classification number (PCN) of 6, in order to allow the operation of a Cessna Caravan aircraft, which resulted in 294 (two hundred and ninety-four) local aerodromes, which are the subject of this research.

In terms of city size, 69.0% (203 aerodromes) were located in small cities, 29.3% (86 aerodromes) in medium-sized cities, and 1.7% (5 aerodromes) in large cities. The IBGE (Brazilian Institute of Geography and Statistics) classifies cities based on the number of inhabitants, using the following categories: small (up to 99,999 inhabitants), medium (between 100,000 and 499,000 inhabitants), and large (over 500,000 inhabitants).

To estimate the probability of a flight existing at a local aerodrome, we opted to apply a binary logit model, as presented in Equation 1, given as a function of an independent term, a set of explanatory variables, xi, and an error term εi. In this model, the estimated values of the dependent variable will be between zero and one. (Gujarati; Porter, 2011; Washington et al., 2020):

$$P_i = \frac{1}{1+e^{-(\beta_1+\sum \beta_i x_i+\varepsilon_i)}} \quad (1)$$

In addition, the model incorporates nonlinear effects, and its estimated coefficients will show the implication of each of the dependent variables, as in a linear regression. The idea is that these values of the unknown coefficients are obtained so that the probability of the dependent variable data is as high as possible, in such a way that the likelihood function given in Equation 2 is maximized:

$$f(Y_1, Y_2, Y_3, \dots y_n) = \prod_1^n P_i^{Y_i} (1 - P_i)^{Y_i} \quad (2)$$

To obtain the odds ratio, which is given by dividing the probability of the event occurring (P1) by the probability of it not occurring (1 - P1), simply take the antilogarithm, as given by Equation 3 below.

$$\frac{P_i}{1-P_i} = e^{\beta_1+\sum\beta_i x_i+\varepsilon_i} \rightarrow P_i = \frac{1}{1+e^{-(\beta_1+\sum \beta_i x_i+\varepsilon_i)}} = \frac{e^{(\beta_1+\sum \beta_i x_i+\varepsilon_i)}}{1+e^{(\beta_1+\sum \beta_i x_i+\varepsilon_i)}} \quad (3)$$

When the logit function (, da Equação 3) has a positive sign, the probability of event Pi occurring is directly proportional to the regressor; if one increases or decreases, the same happens with the other, in such a way as to approach or move away from 1, respectively. When the sign is negative, the relationship becomes inversely proportional, now approaching or moving away from zero. (Gujarati; Porter, 2011; Washington et al., 2020).

Finally, there is elasticity, which is measured by considering a percentage unit of variation in the repressor and will show how intensely each variable impacts the odds ratio of the event defined in the model.

The logit models proposed to study whether there were flights at a local aerodrome in each region of the country were based on the independent variables listed in Table 2:

Table 2 | Variables used in the model for Brazil and each of its regions

Variables	NE	N	CO	S	SE	BRAZIL
UAA ≥ 1000 (S/N)		x	x		x	x
Length	x	x	x	x	x	x
Population					x	x
Population ≥ 75.000	x			x		
Belém-Manaus axis (S/N)		x				x
North (S/N)						x
Northeast (S/N)						x
Midwest (S/N)						x
South (S/N)						x

Equation (4) presents the logit model used, whereby for each region of the country, or Brazil as a whole, only the variables indicated in Table 2 should be used:

$$L_i = ln\left(\frac{P_i}{1-P_i}\right) = \beta_1 + \beta_2.UAA1000_i + \beta_3.Comprimento_i + \beta_4.Pop_i + \beta_5.Pop75000_i + \beta_6.Eixo\_Belem\_Manaus_i + \beta_7.R\_Norte_i + \beta_8.R\_Nordeste_i + \ + \beta_9.R\_C\_Oeste_i + \beta_{10}.R\_Sul_i + \varepsilon_i \quad (4)$$

Where:
L_i = flight occurrence (1 – yes or 0 – no);
, attribute coefficients;
$UAA1000_i$ – Airport aeronautical unit ≥ 1000 (1- yes or 0 - no);
Length – length of the runway divided by 100;
Pop_i - population;
$Pop75000_i$ – population ≥ 75000 (1 - yes or 0 - no);
$Axis\_Belem\_Manaus_i$ – (1- yes or 0 - no);

R_North_i – airfield belongs to the North region (1 - yes or 0 - no);
$R\_Northeast_i$ – airfield belongs to the Northeast region (1 - yes or 0 - no);
$R\_C\_West_i$ – airfield belongs to the Midwest region (1 - yes or 0 - no);
R_South_i – airfield belongs to the South regionl (1 - yes or 0 - no); e,
is the random error of the function.

Next, brief discussions will be held on the independent variables of the logistic regression model, followed by an analysis of their marginal effects, also known as elasticities. The results and their interpretations will then be presented, along with a robustness analysis and comments on random errors.

RESULTS AND DISCUSSIONS

The domestic airline market is concentrated and highly complex, dominated by three airlines (LATAM, GOL, and AZUL), each of which holds approximately one-third of the market (ANAC, 2022). Each of these players has a different business strategy, which influences the establishment and management of their respective airline networks. These companies will be referred to by letters when specific information about any of them is provided.

While Company Y opted for a fleet consisting entirely of medium-sized Boeing 737 aircraft (700 NG, 800 NG, and Max 8) with an average capacity of 120 seats, Company Z already has a greater diversity of models, with Boeing (767, 777, and 787) and Airbus (319, 320, and 321) aircraft with an average capacity of 140 seats.

Company X has the most diverse fleet, with medium-sized aircraft (A-320, Embraer 190, and 195) and large aircraft (A-330), as well as smaller aircraft (Caravan – 9 passengers, ATR 72-600 – 72 passengers), which provides flexibility in planning and makes it easier to reach and/or test new potential markets, checking and adjusting supply and demand.

Considering that the survey uses 294 aerodromes, classified by size, according to the PAN (2018) and Appendix XI of the PAN (2024) and the conditions previously established in the methodology, it is interesting to check in Table 3 which aerodromes were operated by the three major airlines from January 2020 to December 2024.

Table 3 | Number of airports operated by airline and per year, according to size

	AIRLINE Z					AIRLINE Y					AIRLINE X					Exist(*)
ANO	20	21	22	23	24	20	21	22	23	24	20	21	22	23	24	
Large Hub	20	20	20	21	21	20	20	20	21	21	20	20	20	21	21	21
Hub medium	18	18	18	17	17	17	17	17	17	17	18	16	18	17	17	17
Hub small	9	11	11	18	16	20	20	18	18	19	27	26	27	22	22	22
Local	1	4	2	2	3	5	5	4	9	9	87	64	68	99	103	239
Others	1	1	1	0	1	1	1	0	0	1	18	20	9	6	9	419
Total:	49	54	52	58	58	63	63	58	65	67	170	146	142	165	172	718

(*) Apendix XI, of PAN 2024

Source: PAN (2018), PAN (2024), ANAC (2025)

It can be observed that each of the three players operated all major hubs and almost all medium-sized hubs. Regarding small hubs, Company Z increased its share over the years, Company Y maintained a relatively constant share, and Company X showed a slight decline, but still operated in more airports than its competitors. When we looked at local aerodromes, Company X was pretty much the only one operating a significant portion of local aerodromes, considering a total of approximately 240 aerodromes (PAN, 2024).

The explanation can be based mainly on each company's fleet, as medium-sized aircraft, such as those used by Company Z and Company Y, require better runway conditions (longer, wider, more resistant). Thus, Table 4 presents the physical characteristics of local airports and the Canoas – RS and UNA-BA (others) aerodromes operated by each of these companies, which reinforce the argument presented.

Table 4 | Number of airports operated by airline and per year, according to size

airport	runnaway	airline y					airline Z				
		20	21	22	23	24	20	21	22	23	24
Araçatuba - SP	2.120 m x 35 m				x	x					
Bonito – MS	2.000 m x 30 m			x	x	x					
Cabo Frio – RJ	2.550 m x 45 m	x	x					x			
Caldas Novas - GO	2.100 m x 30 m				x	x					
Canoas – RS (outros)	2.751 m x 45 m					x					x
Cruz - CE	2.200 m x 45 m	x	x	x				x	x		
Cruzeiro do Sul – AC	2.400 m x 45 m	x	x	x	x	x					
Dourados - MS	1.950 m x 30 m	x	x								
Parintins - AM	1.800 m x 30 m					x					
Pelotas - RS	1.980 m x 42 m			x	x	x					x
Santo Ângelo - RS	1.625 m x 30 m				x	x					
São Carlos - SP	1.720 m x 45 m						x	x	x		
São José dos Campos - SP	2.676 m x 45 m	x	x		x	x		x		x	x
Una – BA (outros)	2.000 m x 30 m	x	x		x		x	x	x	x	x
Uberaba – MG	1.759 m x 45 m				x	x					

Source: PAN (2018), PAN (2024), ANAC (2025)

Considering that the air network can still be greatly expanded if local airports are included, it is clear that there is significant market potential to be explored.

The implementation of new routes can have a direct impact on the region's development: economy (job creation, tax collection, increased business); tourism, if the region has the potential; integration and accessibility, with improved access to health services and/or reduced isolation of remote regions, among many other benefits.

From the literature, the variables: population, GDP, GDP/per capita, GDP of the tertiary sector, HDI, number of companies, salaried employees, and tax collection are always used when analyzing the feasibility of opening a new route or the probability that a city will have a certain type of service, as they indirectly represent proxies for the region's economic development. However, in the research data sample (local aerodromes), they proved to be strongly correlated, which led to only the population variable being considered.

Thus, when looking at the size of the cities, of the 95 (ninety-five) that had flights, 36 (thirty-six) were medium-sized cities (38.3%) and 54 (fifty-four) were small cities (57.4%), many of which had populations above 75,000 inhabitants, close to becoming medium-sized cities, corroborating that the growth of these municipalities contributes to changes in regional urban dynamics in the states, including changes in the organization and functioning of their urban network (Jardim; Silveira, 2020).

Other variables that measure tourism potential, such as: number of domestic tourists, number of tourism establishments and jobs, tourism tax revenue, and tourism region classification, according to the Ministry of Tourism, were tested for data from the Northeast region, but were not significant and were not considered. One possibility is that current tourist routes are already well established and cover the main points of the country, so local airports would not be essential for accessing these tourist regions.

Location variables were also tested, such as whether the city was within the catchment area of a hub airport, or the distance in kilometers from the nearest airport with regular flights. However, these variables were also not significant.

Finally, among all regions, the North region has a particular development feature, as accessibility, which is mainly achieved by river transport, has its highest flow on the Belém–Manaus axis. So, to try to capture this effect and contribute to the explanation of the model as to whether or not there were flights at a given aerodrome, a dichotomous variable was created if the runway was in the vicinity of the river corridor between those two capitals.

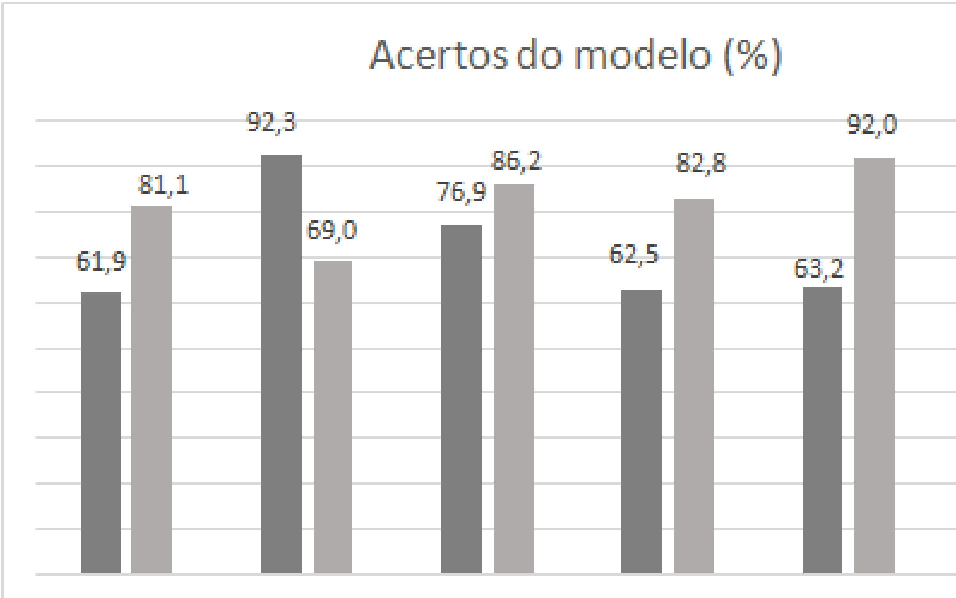
Considering the variables discussed above for the construction of the binary logit model presented in the Methodology section, Table 5 shows the coefficients and their significance (p-value) for the models of each region and also for Brazil.

Table 5 | Parameters and significance of the model variables for Brazil and each of its regions

Variables	NE	N	CO	S	SE	Brazil
Constant	-7,75**	-6,455**	-6,681*	-4,224*	-5,807**	-7,874***
UAA ≥ 1000 (S/N)		3,903***	2,713**		3,420**	4,320***
Length (e-2)	0,431**	0,216*	0,276 º	0,172	0,117	0,199**
Population					1,81e-6	1,52e-6
Populati on≥ 75.000	1,659*			1,811*		
Axis Belém-Manaus (S/N)		0,467				0,416
Norrth region (S/N)						1,227 º
Northeast region (S/N)						1,992**
Midwest region (S/N)						1,2087 º
South region (S/N)						1,452*
R^2 de McFadden	30,85%	41,67%	37,49%	17,47%	40,8%	52,5%
Acuracy observed (AcObs)	74,1%	80,0%	83,3%	75,6%	86,2%	86,7%
Acuracy expected (AcEsp)	0,543	0,495	0,563	0,548	0,683	0,542
Coeficient Kappa (K)	0,434	0,604	0,618	0,459	0,563	0,710
Plausibility ratio	23,42***	31,70***	19,48***	10,24**	38,62***	194,24***
	*** p <0, 1%	** p < 1%	* p < 5%	º p <10%		

For each region, the model calculated the percentage of cases correctly predicted for airports that had air operations (> 61%) and those that did not (> 69%), as shown in Graph 1. It can be seen that the model for the Midwest region was the most accurate (K = 0.618) compared to the other regions. Considering the country as a whole, the percentages were 88.4% for those that had operations and 85.9% for those that did not.

Graph 1 | Forecast provided by models for flights at aerodromes in each region of Brazil



INTERPRETATION OF MODELS

The six models, five regional and one national, presented eleven significant variables: two with significance below 0.1%; five significant at 1%; and four significant at 5%. It is also noted that there are three variables with marginal significance (between 5% and 10%). The most recurrent variable for predicting whether an aerodrome operated flights during the study period was: UAA% > 1000, which appeared in four models, and the runway length variable, which also appears in four models, but with one of the significances being marginal.

All variables showed positive signs indicating that as their value increases, the chances of flights occurring at the municipality's aerodrome also increase. For every 100 m increase in runway length, aerodromes in the Northeast region are 1.5 times (exp(0.431)) more likely to operate flights, those in the North 1.2 times (exp(0.216)), those in the Midwest 1.3 times (exp(0.276)), and those in the Brazil model 1.2 times (exp(0.199)).

When considering the population ≥ 75,000 inhabitants (Y/N), aerodromes in the Northeast region are 5 times (exp(1.659)) more likely to operate flights and those in the South are 6 times (exp(1.818)) more likely, however, when considering the population (number of inhabitants), the variable was not significant for the approach of this study.

In the North region, when the variable UAA ≥ 1000 (Y/N) is verified, the odds are increased by 49 times (exp(3.903)); in the Central-West region, 15 times (exp(2.713)); in the Southeast region, 30 times (esp(3.420)), and in the Brazil model, 75 times (ex(4.320)). In addition, it was observed that neither in the North region nor in the Brazil model was the Belém-Manaus Axis (Y/N) variable significant.

Finally, considering the Southeast region as a basis for comparison between the country's regions, the chances of there being flights in all other regions are greater. Assuming analyses of each model, the probabilities of having air operations at aerodromes can be found in Table 6, showing consistency with the Brazil model, as it follows the same order between regions.

Table 6 | Probability of flights by region of the country

Region	Probability of flights (%)
North	47,27
Northeast	36,21
Midwest	30,95
Southeast	20,21
South	35,56
Brazil	32,31

One possible explanation for why the Southeast region, which is the most developed in the country, has the lowest probability of operating flights at local airports is the greater presence of large hubs in the country: seven of the twenty-one existing ones. Thus, these hubs, with their catchment areas, end up inhibiting or delaying the development of local airports in their vicinity. In addition, it is worth noting the excellent road connection system in the Southeast region, which ultimately favors the use of road transport as a substitute for air transport and also contributes to the concentration of the air network in certain nodes following, their own geographical patterns, which are not the subject of this study.

ROBUSTNESS OF MODELS

Tests were performed on the autocorrelation of all models, which showed no correlation between variables.

After considering the classification table for observed data versus predicted data for each model, also called the confusion matrix, given by Equation (5) below:

$$\text{Matriz de Confusão:}\quad \begin{matrix} & 0 & 1 \\ 0 & x & y \\ 1 & w & z \end{matrix} \qquad (5)$$

the observed accuracy (AcObs) and expected accuracy (AcEsp) were calculated, and the models were evaluated using the Kappa statistic (K), according to Formulas (6), (7), and (8) below:

$$AcObs = \frac{x+z}{x+y+w+z} \qquad (6)$$

$$AcEsp = \frac{(x+y).(x+w)+(z+w).(z+y)}{(x+y+w+z)^2} \qquad (7)$$

$$K = \frac{AcObs - AcEsp}{1 - AcEsp} \qquad (8)$$

The advantage of the K measure is that it allows different models used for the same classification task to be compared with each other, such that the more accurate the model, the higher the value of K.

Considering the five regions, it was noted that the models for the Midwest and North regions were those that revealed the highest K values, 0.618 and 0.604, respectively, while for the country as a whole, the value was 0.710. According to Landis and Koch (1977), the models for the North, Midwest, and Brazil regions showed a good level of agreement, $0.60 < K < 0.80$, and the other models showed a moderate level of agreement, $0.40 < K < 0.60$.

DISCUSSION ABOUT RANDOM ERRORS

In any model used to explain a phenomenon, there is an inherent margin of error that needs to be explored, mainly to understand how it can be improved or exploited and analyzed in a more transparent way. Errors can be caused by a lack of information on a variable in the databases used, or the omission of consideration of some variable, or even information that was not known to the researcher during the preparation of the research and that affects the construction of the model.

It should be noted that variables such as the opening of a subsidiary of Company X may have influenced the increase in the number of regional airports operating, based on a new strategy adopted by this subsidiary, which began to focus mainly on operating new, previously unexplored destinations. To this end, it relied on a fleet of seventeen Cessna Caravan aircraft, fourteen of which were passenger aircraft and three were cargo aircraft. However, this company's entry into the market was not analyzed separately by this study, with flights being counted as linked to the parent company.

The study considered whether municipalities with local aerodromes operated flights at any point between 2020 and 2024, but did not analyze whether this operation was continuous, seasonal, or even for testing by the airline, lasting only one or two months. This situation can be explored in further studies.

Another factor that was not explored in the model, due to its difficulty in measurement, was the agreements between state governments and airlines to stimulate the development of passenger and cargo transport in the states and guarantee routes in certain cities, in exchange for tax exemptions, such as on aviation fuel. This allowed for the agreement of previously determined destinations that would otherwise likely not be served, including local aerodromes, which are the subject of this article. Among the states are: São Paulo and Mato Grosso do Sul, starting in 2019; Rio Grande do Sul, 2020; Rio de Janeiro and Amazonas, 2021, among others.

There may be other political, economic, and social factors, however, the objective is not to verify all possibilities, but rather to make the reader aware of specific aspects that may need to be analyzed more carefully to avoid the appearance of biases in the model.

CONCLUSION

The complexity of the aviation market is one of the biggest challenges facing players in the sector, as it requires constant improvement of the services provided, the continuous search for new business opportunities, and the development of creative solutions, attributes that are being thoroughly tested in this time of pandemic, rising commodity prices, and global inflationary crisis. Automation of passenger boarding process stages, restructuring of the airline network with the closure/suspension of some existing routes and/or opening/testing of new destinations in unexplored markets, and virtual boarding queues were some of the new processes implemented during this turbulent period.

In this environment, considering the performance of the airline industry in relation to the airline network, the following questions were raised: Are there new aerodromes that have the potential to be exploited by airlines? Which aerodromes would these be, and what are their common characteristics? In which regions of the country are they most concentrated? To help answer these questions, this study, based on the PAN (2018) and PAN (2024) and ANAC data, developed a binary logit model to explore the subject.

Thus, the main objective of this article is to propose a way to identify the factors that increase the likelihood of a small airport or local airport that is not classified as a hub by the National Air Plan to operate, so that this information can be used by all players in the aviation sector, whether planners, operators, managers, public officials, or administrators, with a view to increasing the efficiency of air network management and assisting in the formulation of public policies.

It was observed that local aerodromes are well distributed across the country's regions, with a slightly higher concentration in the Southeast, probably because it is the most developed region in the country. In the models developed, the most significant variables that stood out, considering Brazil and each of its regions, were: population, airport aeronautical unit (UAA), and runway length.

These factors showed that they increase the chances of flight operations when cities in the Northeast and South regions have populations exceeding 75,000 inhabitants; when in the North, Central-West, Southeast, and Brazil model regions, the UAA exceeds 1,000; and finally, when in the Northeast, North, Central-West, and Brazil model regions, the length of the landing strip is increased.

When analyzing the regions of the country, the North region was the one with the highest probability of local aerodromes operating flights. On the other hand, the Southeast region was the one with the lowest probability, probably due to the concentration of large hubs (seven of the twenty existing in the country), which disadvantages operations at local aerodromes, as already explained in the previous section.

As with any model presented, there are limitations, since variables such as the opening of Company X's subsidiary to serve regional markets from August 2020 onwards, or agreements with state governments to establish routes in exchange for tax rate reductions, were not explored. In addition, the duration and frequency of existing connections were not analyzed, only whether they existed at some point, in order to calculate whether the local airport operated flights or not.

These limitations may be the subject of future studies to improve this work. In addition, further studies are suggested on the evolution of hub sizes and how they are associated with the economic development of host cities, or research related to the evolution of air network connectivity in each region of the country, based on the entry of local airports, as topics of great interest that are still largely unexplored.

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