EFFICIENCY ASSESSMENT OF CENTRAL AIRPORTS IN BRAZIL

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ABSTRACT
In this paper, we asses the efficiency of Brazilian airports, based on Data Envelopment Analysis (DEA). Although previous studies applied DEA to Brazilian airports, herein we consider DEA´s homogeneity assumption, according to which units are assumed to operate in similar environments. As airport environment differs significantly throughout the country, we limit our analysis to six central airports. Still, our results are valuable nationwide, because these airports handle half of all flights departing from Brazil. As classic DEA is not recommended for small data sets, we use Multiple Criteria DEA, which has more discriminatory power. In our study, we found that only two airports in the State of São Paulo are efficient, whereas the other central airports are under-utilized, with an efficiency score of less than 50%. Results found in this study could serve as an important tool for public politics, as well as for private decisions in the airport sector.

KEYWORDS. Airport efficiency; central airports; Brazilian air transport; Multiple Criteria Data Envelopment Analysis.

MSC: 90B06

RESUMEN
En este documento, evaluamos la eficiencia de los aeropuertos brasileños, según el Data Envelopment Analysis (DEA). Aunque estudios previos aplicaron DEA a aeropuertos brasileños, aquí consideramos el supuesto de homogeneidad de DEA, según el cual se supone que las unidades operan en entornos similares. Como el sítio aeroportuario difiere significativamente en todo el país, limitamos nuestro análisis a seis aeropuertos centrales. Aún así, nuestros resultados son valiosos en todo el país, porque estos aeropuertos manejan la mitad de todos los vuelos que salen de Brasil. Como la DEA clásica no se recomienda para conjuntos de datos pequeños, utilizamos la DEA de Multiple Criteria DEA (MCDEA), que tiene más poder discriminatorio. En nuestro estudio, encontramos que solo dos aeropuertos en el estado de São Paulo son eficientes, mientras que los otros aeropuertos centrales están infrautilizados, con una puntuación de eficiencia inferior al 50%. Los resultados encontrados en este estudio podrían servir como una herramienta importante para las políticas públicas, así como para las decisiones privadas en el sector aeroportuario.

PALABRAS CLAVE: eficiencia aeroportuaria, aeropuertos centrales, análisis envolvente de datos multicriterial.

1. INTRODUCTION

In Brazil, there are approximately 2,498 airports (including landing areas), i.e., the second largest number of airports in the world, only behind the United States. However, only 128 of them are commercially explored. Moreover, only three airports are rated among the top 100 in the world, and the quality of Brazilian airport infrastructure is ranked by executives in 19th place, out of 23 countries from Latin America and Caribbean, and 112th place, globally (IATA, 2016).

Considering that airport infrastructure highly influence air transport efficiency (Assis *et al.,* 2017), in this paper, we evaluate airport efficiency in Brazil, using a methodology based on Data Envelopment Analysis (DEA). DEA is particularly indicated for this study, because Brazilian airports are public, as well as monopolies in their regions, and consequently, their input and output prices are distorted (Fare *et al.,* 1985).

However, the environments of Brazilian airports vary significantly throughout the country, such as population concentration, economic and financial aspects, demand for air services, etc. This contradicts DEA´s homogeneity assumption, according to which DMUs are assumed to operate in similar environments (Dyson *et al.* 2001). This is why we limit our analysis to six central airports in Brazil (*Guarulhos*, *Congonhas*, and *Viracopos* in the State of *São Paulo*, *Brasilia* in the Federal District, *Galeão* in the State of *Rio de Janeiro*, and *Confins* in the State of *Minas Gerais*), studied in Pereira (2015), with closer environmental characteristics. Despite this limitation, our results are still valuable nationwide, because together these central airports concentrate 50% of all flights in Brazil (Pereira, 2015).

On the other hand, classic DEA models are not suitable for small data sets (Cooper *et al*., 2001). Therefore, we use a Multiple Criteria Data Envelopment Analysis (MCDEA) model, proposed by Li & Reeves (1999), to improve discrimination and provide relevant information on airport efficiency. Moreover, we calculate the

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MCDEA-TRIMAP Efficiency index proposed by Soares de Mello *et al*. (2009) to obtain an efficiency value for each airport, as well as a final ranking.
In the next section, we present a literature review regarding air transport DEA studies. In section 3, we detail the theoretical background which supports our current analysis, including the Multiple Criteria Data Envelopment Analysis (MCDEA) model and the methodology that calculates efficiencies based on MCDEA. In section 4, we describe the study case of the main airports in Brazil, presenting and discussing the main results from the MCDEA model. In the last section, we present conclusions of this paper.

2. LITERATURE REVIEW

There are various papers on airport efficiency, most of which are based on DEA or Stochastic Frontier Analysis (SFA) (Wanke & Barros, 2017). For a comprehensive survey on airport productivity and efficiency studies, see for instance Liebert & Niemeier (2013), who surveyed methods, data and findings of empirical research. Although Pels *et al.* (2001), who studied efficiency of European airports, obtained similar results from both methodologies, still, they present different strengths and weaknesses.
SFA focuses on the economic justification of a given production function, and provides robust examination of the roots for inefficiencies (Bogetoft & Otto, 2010), although it is a parametric method, which requires distributional assumptions. On the other hand, DEA does not perform well with regard to statistical properties (Wanke & Barros, 2017), tough it is indicated for cases where input and output prices are distorted by market power or government restrictions (Fare *et al.,* 1985). This is the case of airports, which are monopolies for their regions (Abbott, 2015). For a recent review on airport efficiency papers using DEA, see Wanke *et al*. (2016), for instance.
In Latin America, Perelman & Serebrisky (2012) assessed technical efficiency of airports, using DEA and the Malmquist Productivity Index. The authors highlighted that the private sector injected over 9 billion dollars in Latin American airports, between 1998 and 2008, yet there were not many studies on airport efficiency in the region. They analysed 21 airports that accounted for 80% of total passengers and 70% of total air cargo in Latin American. Among them, there were three airports in *São Paulo*, and also those in *Brasilia*, *Manaus* and *Rio de Janeiro*.
Perelman & Serebrisky (2012) considered as outputs number of passengers, tons of freight and number of aircraft movements, and as inputs number of employees, number of runways and terminal size. Results show that two airports from *São Paulo* (VCP and CGH) are efficient in both time periods (2000-2003 and 2004-2007), even in the DEA model with constant returns to scale (CCR – Charnes *et al*., 1978). The other airport from *São Paulo* is efficient in both periods, though only in the DEA model with variable returns to scale (BCC – Banker *et al*., 1984). The airport in *Brasilia* is efficient only in the BCC model for the first period, and suffers a significant efficiency decrease in the second period, as a result of airport expansion (number of runways, terminal size and number of employees). The airports in *Manaus* and in *Rio de Janeiro* are inefficient in all models.
In Brazil, Pacheco & Fernandes (2003) used a BCC input-oriented model to analyse 35 airports with predominant domestic traffic in 1998. The authors considered as outputs domestic passengers, tons of cargo and mail, operating revenue, commercial revenue, and other revenues; and as inputs average number of employees, payroll, and operating expenses. Their studies found 10 efficient airports, including in *São Paulo, Belo Horizonte* and *Rio de Janeiro*.
Pacheco & Fernandes (2003) compared their results of management efficiency with those of Fernandes & Pacheco (2002), who studied the capacity efficiency of the same Brazilian airports, considering the number of domestic passengers as the single output, and as inputs area of apron, departure lounge, number of check-in counters, curb frontage, number of vehicle parking spaces, and baggage claim area. This comparison is worthwhile, as high operational usage of airports usually results in advantages regarding scale economics, and also increases the costs for congestion (Sheard, 2017). Pacheco & Fernandes (2003) classified the observed airports into four categories, according to their efficiency results from both studies. *São Paulo, Belo Horizonte*, and *Rio de Janeiro,* among others, were considered "stars", i.e., presented high managerial efficiency, and were also at their physical capacity limit.
Wanke (2012) analysed 65 Brazilian airports in 2009, using DEA and the Free Disposal Hull (FDH) model, as well as the bootstrap methodology to account for measurement errors, for the ten largest passenger airports. This study considers the number of landings and takeoffs as the single input, and as outputs, the number passengers, and weight of cargo and mail. Although the input variable seems different from other papers, Wanke (2012) explained that correlation analyses justify the choice of variables.

Wanke (2012) found 5 efficient airports, using the CCR model, namely, *Galeão* in *Rio de Janeiro*, *Guarulhos* and *Campinas* in *São Paulo*, *Manaus* in the State of *Amazonas*, and *Teresina* in the state of *Piauí*. The BCC model found one other efficient airport, that is, *Bagé* in the state of *Rio Grande do Sul*. With the Bootstrap procedure, considering the convexity assumption and the upper bounds for the 95% confidence intervals, only *Galeão*, *Campinas* and *Guarulhos*, out of the ten largest airports, had unitary distance functions. However, the convexity assumption was statistically rejected for five DMUs.

In this paper, we take into account the homogeneity assumption in DEA, i.e., DMUs are assumed to operate in similar environments (Dyson *et al.* 2001). In fact, Brazil is significantly diverse in various aspects, which lead to different airport conditions throughout the country. Thus, we understand that DEA studies of limited groups of airports, under similar circumstances, are more valuable to managers and other interested parties than studies that aggregate all or many Brazilian airports.

Therefore, this paper studies the efficiency of central airports in Brazil, which undertake a significant proportion of national flights and are also important connection points to other places in the country. By limiting the analysis to such group, our paper compares airports with similar external characteristics, while providing useful analyses for the entire country.

On the other hand, DEA models with few DMUs have poor discriminatory power and could provide distorted results (Cooper *et al*., 2001). Therefore, in this study, we apply the Multiple Criteria Data Envelopment Analysis (MCDEA) model, proposed by Li & Reeves (1999). This model introduces additional objective functions to increase discrimination in DEA models, as explained in the next section.

3. THEORETICAL BACKGROUND

3.1 DEA and MCDEA

Data Envelopment Analysis (DEA) is a nonparametric mathematical programming problem that calculates the efficiencies of Decision Making Units (DMUs), considering their resources (inputs) and products (outputs). Standard DEA models calculate the multipliers for inputs and outputs of each DMU, so that its efficiency is maximized, following the model´s restrictions. Although this is a central characteristic in DEA models, it could lead to distorted results, such as efficient DMUs that attribute null multipliers for several inputs and/or outputs. Another consequence of such benevolence is the low discriminatory power of standard DEA, particularly for problems with few DMUs, compared to the number of inputs and outputs.

To solve both problems, Li & Reeves (1999) proposed a multi-objective model, based on the DEA model with constant returns to scale, called MCDEA. This model preserves the classic objective function and introduces two additional objective functions: one that minimizes the maximum deviation ($Min\ Max\ d_k$) and the other that minimizes the sum of deviations ($Min\ \sum_{k=1}^{n} d_k$). According to Li & Reeves (1999), all three objective functions are independent and equally important. Model (1) presents the linearized version of the MCDEA model, where $Min\ Max\ d_k$ is replaced by $Min\ M$, together with the constraint $M - d_k \geq 0$. Moreover, u_j, v_i are, respectively, the multipliers for outputs $j = 1, \dots, s$ and inputs $i = 1, \dots, r$; y_{jk} and x_{ik} are respectively the values for output j input i of DMU $k = 1, \dots, n$.

$$
\begin{aligned}
& Min\ d_o \\
& Min\ M \\
& Min \sum_{k=1}^{n} d_k \\
& st \sum_{i=1}^{r} v_i x_{io} = 1 \\
& \quad \sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} + d_k = 0, \qquad k = 1, \dots, n \\
& \quad M - d_k \geq 0, \qquad k = 1, \dots, n \\
& \quad u_j, v_i \geq 0, \quad \forall j, i
\end{aligned}
\tag{1}
$$

A DMU is considered mini-max efficient if and only if $d_o = 0$ for the solution that minimizes the second objective function; and mini-sum efficient if and only if $d_o = 0$ for the solution that minimizes the third objective function (SOARES DE MELLO *et al*., 2009). DMUs that are mini-max or mini-sum efficient are also efficient in standard DEA, though the reverse is not true. Hence, both additional objective functions limit the possibilities of multipliers for efficient DMUs.

3.2 TRIMAP and the MCDEA-TRIMAP efficiency index

The TRIMAP software, developed by Clímaco & Antunes (1987, 1989) is a free search method that provides the set of non-dominated solutions in tri-criteria linear programming problems, through a learning process.
Besides computing all optimal solutions for MCDEA´s three objective functions, TRIMAP also presents graphical representations, one of which is very useful for MCDEA, namely the weights space decomposition. This representation shows the indifference regions of the weights space that correspond to the non-dominated basic solutions. These weights refer to the multipliers of the objective functions, and in indifference regions, these weights could vary without altering the solution.
With such tool, it is possible to evaluate whether the DMUs´ optimal evaluations have stable solutions or if they depend on specific multipliers. Large indifference regions indicate that the solution remains the same even with moderate changes of the objective function´s weights. Moreover, it is possible to identify potentially good solutions, which improve results for the second and third objective functions, even if they do not confer the DMU´s maximum efficiency, for instance.
In view of all these possible analyses, Soares de Mello *et al.* (2009) developed the MCDEA-TRIMAP efficiency index, shown in (2), which considers all possible infinite combinations of the objective functions weights.

$$I(Eff_{MCDEA-TRIMAP}) = 1 - (\oiint FO1(\lambda_1, \lambda_2, \lambda_3) dS) / area\ of\ the\ \Delta \qquad (2)$$

In (2), $FO1$ is the value of the classic objective function of model (1), and $\lambda_1, \lambda_2, \lambda_3$ are the weights assigned for the first, second and third objective functions. In words, the proposed index is based on the integration of $FO1$ throughout the entire weights space, where the combination of the objective functions weights varies continuously. We divide this result by the space size to obtain the average of $FO1$. Finally, the efficiency index is the complement of this value.
Although index (2) seems complex, we should highlight that the integration's value is constant inside each indifference region. Thus, the index is simply the complement of the "weighted" sum of the classic objective function values, in which the "weights" are the percentages of the total area where each solution is valid. The MCDEA-TRIMAP efficiency index of a DMU is never higher than its standard DEA efficiency (Soares de Mello *et al*. 2009).
To avoid distortions in the weights space integration, Soares de Mello *et al.* (2009) proposed a slight modification to the third objective function, without affecting any solutions. The authors divided the sum of deviations by the number of DMUs, so that all objective functions measure the deviation of a single DMU.

4. EFFICIENCY OF CENTRAL AIRPORTS IN BRAZIL

In this section, we present our case study on Brazilian airport efficiency. As consequence of DEA´s homogeneity assumption, our evaluation is focused on central airports, which represent the majority of flights. We should highlight that, hereinafter, we use certain concepts of graph theory, which could be found in Bondy & Murty (2008).

4.1 Central Airports

Among other studies of airport centrality and connectivity, such as Malighettia *et al.* (2008), Paleari *et al*. (2010) and Allroggen *et al.* (2015), Pereira *et al*. (2018) checked the network of a Brazilian airline company using some centrality measures to determine central airports for this company. The authors considered regular commercial flights (domestic and international) for passenger transportation as well as for cargo load. Data were obtained from Monday departures in June, 2015. The authors excluded freight flights and the postal network service, because of their low impact on air transport operation in Brazil.
In another approach, Pereira (2015) analysed the main network of Brazilian airports, using a centrality model based on the h-index (Hirsch, 2005), called h-centrality. Besides measuring the influence of each vertex on neighbours, as other centrality measurements, the h-centrality also verifies the dispersion of such influence. Based on the official Transport Schedule table by the National Civil Aviation Agency (ANAC – *Agência Nacional de Aviação Civil,* in Portuguese, available at http://www.anac.gov.br/assuntos/setor-

regulado/empresas/registro-de-servicos). We considered domestic and international regular commercial flights from 104 airports, occurred on Monday, 8 August, 2015.
Results show that the general *h*-index for Brazil is six, i.e., there at least six airports with h-index greater or equal to six. In this paper, we consider the central airports found in Pereira (2015): Guarulhos (GRU), Congonhas (CGH), Brasilia (BSB), Galeão (GIG), Confins (CNF) and Viracopos (VCP). Here, the code for each airport follows the IATA standards. These airports represent more than 50% of the flights approved. It is worth highlighting that three of these airports (GRU, BSB and GIG) are among the top 100 airports in the IATA global ranking (IATA, 2016).
Five of these airports are located in the Brazilian Southeast Region, which represents 49% of total flight, according to ANAC (2016). Namely, GRU, CGH and VCP are in the State of São Paulo, GIG, in Rio de Janeiro and CNF, in Minas Gerais. These States have the country´s highest GDPs. The richest of them, São Paulo, is responsible for almost 30% of all Brazilian flights (Pereira, 2015). BSB is located in Brasilia, the Brazilian Capital, in the Midwest Region. It is considered a hub for politicians and for flights connecting interior regions, as well as international flights.
We consider as input the total area of the airport site, and as outputs, the following variables: (1) the number of companies that operate in the airport, (2) the number of certificated departures, (3) the weight of departed cargo load, and (4) the number of departed passengers. Table 1 presents the input and output data, from Monday, 8 August, 2015.
The airport site, which represents airport structure, is a common input for airport studies (Perelman & Serebrisky, 2012). With regard to outputs, the number of companies is a good indication of airport size, particularly in terms of its market power, compared to that of airlines (Thelle *et al.*, 2012; Wiltshire, 2013). The number of take-offs, passengers and cargo load represent the airport´s operational utilization and are also in line with most studies from the literature (Perelman & Serebrisky, 2012).

H-Centrality	Airport Site (x10^3)/m²	Airliners	Takeoffs	Cargo Load (x10^3)/t	Passengers (x10^3)
GRU	11905	50	11595	10.26	986
CGH	1647	5	7526	2.21	750
BSB	13774	18	6852	3.70	739
GIG	17881	35	5425	2.16	493
CNF	15120	15	4663	1.09	417
VCP	17659	22	5566	1.01	370

Table 1 – Input and output data for central airports, from the Brazilian Aviation Agency

4.2 Results and Discussions

We use the TRIMAP software to calculate results for the MCDEA model and obtain the weight space decomposition, for each central airport, as explained in section 3. Then, we calculate the MCDEA-TRIMAP efficiency index proposed by Soares de Mello *et al*. (2009) to obtain a single ranking for Brazilian central airports.
To elucidate this procedure, we present the TRIMAP results for *Guarulhos* (GRU). In Figure 1, we show the weight space decomposition for this DMU.

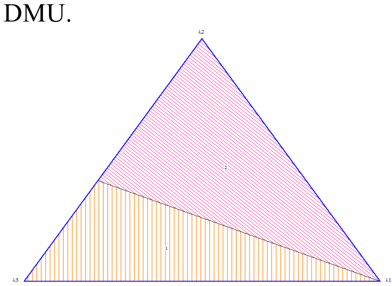

Figure 1 – Weight space decomposition for GRU

In Table 2, we present, for each solution, the values of all objective functions and the size of the indifference region, as well as the MCDEA-TRIMAP efficiency index for GRU. Here, FO1 represents the classic objective function, FO2 represents the objective function that minimizes the average deviation, and FO3 represents the objective function that minimizes the maximum deviation.
From Figure 1 and Table 2, we could observe that GRU is mini-sum efficient (Solution 2), i.e., GRU is efficient with the solution that minimizes the average deviation, and also mini-max efficient (Solution 1), i.e., GRU is efficient with the solution that minimizes the maximum deviation of all DMUs. Moreover, these solutions are very stable in the sense that we could vary the weights attributed to each objective function within a wide range. More precisely, this remains true in 41,3% for Solution 1 and 58.7% for Solution 2 of the weight space decomposition.

GRU	SOLUTION 1	SOLUTION 2
FO1	-	-
FO2	0.695	0.535
FO3	5.459	5.571
AREA (%)	41.273	58.727

Table 2 – MCDEA-TRIMAP efficiency index for GRU

Conducting this procedure for all six central airports, we obtain their efficiency indexes and final ranking, as shown in Table 3.

AIRPORT	MCDEA INDEX
GRU	100,00%
CGH	100,00%
GIG	45,89%
BSB	32,91%
VCP	29,78%
CNF	24,18%

Table 3 – MCDEA-TRIMAP efficiency indexes and final ranking

From Table 3, we may observe that the efficient airports are located in *São Paulo*, followed by the airport in *Rio de Janeiro*, with an efficiency score of less than 50%, and then by the other airports, respectively in *Brasilia*, *São Paulo*, and *Minas Gerais*, with efficiency scores around 30%. This result indicates that, although central, these inefficient airports could still handle more operations, with their current site.
We should point out that BSB and GIG suffered expansions in the past years. In fact, Perelman & Serebrisky (2012) showed that *Brasilia* was efficient in the 2000-2003 period, though considerably inefficient in the 2004-2007 period, due precisely to airport expansion. In other words, BSB´s operations still haven´t increased enough to match its site expansion. The 2008 international crisis and the Brazilian economic crisis that began in 2014 are possible causes for this.
On the other hand, GIG´s expansion took place just before the 2016 Olympics, and was planned for this specific event, which explains its current under-utilisation. Although the data presented in Table 1 is from 2015, constructions began in 2014 (Nogueira, 2014), when GIG´s operation management was transferred to a private company. In other words, the airport site shown in Table 1 is currently the same. In fact, GIG has the largest airport site of all six central airports, with comparatively small output values.
Similarly, the least efficient airport, *Confins* in *Belo Horizonte*, inaugurated a new passenger terminal in December, 2016, enlarging the terminal area over 60% (BH-airport, 2018). However, for this airport expansion, constructions began in October, 2015 (BH-Airport, 2018), that is, after August, 2015, when the data from Table 1 were obtained. On the other hand, the new terminal began to operate international flights, which may compensate for the airport´s site expansion. In fact, it is expected that *Confins* becomes one of the main hubs in Brazil (BH-airport, 2018).

The fact that *Viracopos* in *São Paulo* is not efficient indicates that the number of operations could increase in this highly developed State, even without major investments. If this weren´t the case, expanding one or more airports in this region would be quite urgent.

5. CONCLUSIONS

In this paper, we evaluated the efficiency of Brazilian airports, using a DEA-based methodology. Seeing that their environmental aspects vary significantly throughout the country, conducting a thorough analysis would disregard DEA´s homogeneity assumption. Thus, we concentrated our analysis on six central airports, studied in Pereira (2015), which present similar population concentration, economic and financial aspects, demand for air services, etc. On the other hand, this scope limitation is not a considerable drawback because these central airports correspond to 50% of all flights in Brazil.

We found that two airports in the State of *São Paulo* are the only efficient airports in the country. The other airport in *São Paulo*, as well those in the States of *Rio de Janeiro, Brasilia*, and *Minas Gerais* have an efficiency score of less than 50%. Although the DEA methodology provides comparative results, we could affirm that these inefficient airports are significantly under-utilised. This means that the operations in all of these States could increase, without major investments. However, the least efficient airport, *Confins*, in *Minas Gerais,* was even expanded after we obtained the data for this study.

Increasing the number of operations in these inefficient airports would not only justify their structure and remunerate investments, but it would also relieve the load of efficient airports. With their current structure and number of operations, *Guarulhos* and *Congonhas* require extremely precise planning in various fields (operational, maintenance, etc.), especially because they are central airports, so that eventual problems do not cause chaos in the country´s air transport system.

Future works could study benchmarks and duality in MCDEA.

Acknowledgment: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

RECEIVED: NOVEMBER, 2018.
REVISED: FEBRUARY, 2019.

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