Infrastructure expansion in Brazilian Airports: a slack analysis using a distance friction minimization

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Abstract
The present paper uses DEA and a distance friction minimization (DFM) approach with fixed factors developed by Suzuki and Nijkamp (2011) to assess the fitting between expected demand for the next 25 years and the infrastructure expansion investments announced by Infraero (Brazilian Airport Authority) for Rio de Janeiro International Airport.

Keywords: Brazilian Airports; DEA; DFM with fixed Factors.

Introduction
This paper aims to offer a contribution to the literature by analyzing the efficiency of Brazilian airports using the recent DEA-DFM approach presented by Suzuki and Nijkamp (2011). In particular, specific data regarding a future infrastructure expansion of the Rio de Janeiro International Airport are used to analyze production slacks over the period 2012-2038.

There are several factors that have fostered the present research. First, as far as the authors are concerned, there are few papers analyzing the airport industry using this DEA-DFM approach, despite the increasing number of studies prepared over the past few years. Furthermore, the DEA-DFM approach offers new perspectives regarding a more realistic technological frontier, given that the criteria for comparison are determined by the data itself, by minimizing the distance to the frontier. Second, an investigation of future operational bottlenecks at airports has become important for the Brazilian public authorities, since the lack of pressure at airports to become more competitive and productive as well as insufficient investments in infrastructure over recent years, could lead to capacity shortfalls that are a concern for the forthcoming FIFA World Cup in 2014 and the Olympic Games in 2016 (Wanke, 2012a). Third, with the privatization progress supported by the Brazilian Government, research on infrastructure expansion impacts could provide some ideas for new concession agreements, especially regarding contract terms that link service levels with potential demand growth. Fourth, a non-discretionary (fixed factors) slack-based approach is adopted here rather than a mere focus on efficiency estimate. This approach is particularly interesting to research technical efficiency, as in most real-life situations managers are unable to change input variables over a short term.

The remainder of the article comprises this introduction and more five sections. Firstly, a brief background on the Brazilian airport industry and a general overview of the concession agreement for the Rio de Janeiro International Airport, followed by a quickly discussion of
previous studies that applied Data Envelopment Analysis (DEA) to the airport industry in several countries, including Brazil. The next section brings the most fundamental methodological issues concerning data analysis, with focus to on DFM with fixed factors approach. Following section presents the analyzed data and results discussed in terms of policy implications for the Rio de Janeiro International Airport. Lastly, conclusions and discussion will be stated in the final section.

**Institutional Setting**

Until recently, air transportation in Brazil was regulated and controlled by the Departamento de Aviação Civil (Brazilian Civil Aviation Department - DAC) and investments in airport infrastructure was performed and operated by Infraero, a state owned company linked to the Brazilian government, founded in 1973. Though the Agência Nacional de Aviação Civil (National Agency for Civil Aviation or ANAC) was established in 2005 as a regulatory agency to oversee the civil aviation sector, taking over DAC responsibilities (Fleury and Hijjar, 2008), until 2011 Infraero was still responsible for managing, renovating, building, and providing equipment for all Brazilian airports.

Under pressure from anecdotal evidence suggesting a capacity shortfall in Brazilian airports (Doca, 2011; Chade, 2012; Vieira, 2013), the Brazilian government implemented a sector deregulation/privatization process by the end of the first quarter of 2011, whereby future concessionaires would be responsible for the operation, maintenance and expansion of each relevant airport. The main purpose was to improve airport productivity and efficiency, fund infrastructure projects (especially with private capital), foster competitiveness and extend capital to new shareholders.

The Natal Airport, a small one located in the Northeastern part of Brazil, was the first airport privatized in 2011, and was used as a pilot test prior to granting large scale airport concessions. The Brasilia and São Paulo International Airports were privatized in the following year and, in the fourth quarter of 2013, Infraero and ANAC announced a concession agreement for the Rio de Janeiro International Airport (ANAC, 2013a; 2103b). One of the terms of the lease contract for this latter airport consists in an investment agenda covering infrastructure expansion plans over the next 25 years, most of them under the responsibility of the new operator. A summary of the proposed main improvements to this agreement is shown in Table 1, in order to assist readers to understand its implications regarding future infrastructure:

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<thead>
<tr>
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<tbody>
<tr>
<td>New vehicle parking area</td>
<td>Construction of two new and independent runways</td>
<td>Construction of new passenger terminal and new aircraft parking area</td>
<td>Construction of a new remote boarding and disembarking area</td>
</tr>
<tr>
<td>Expansion of the apron area</td>
<td>Expansion of the apron area</td>
<td>Expansion of the apron area</td>
<td>Expansion of the terminal and the apron area</td>
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<tr>
<td>Expansion of areas intended for support and maintenance activities</td>
<td>Expansion of the vehicle parking area</td>
<td>Expansion of areas intended for support and maintenance activities</td>
<td>Expansion of areas intended for support and maintenance activities</td>
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<td>Improvements to access roads for vehicles</td>
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*Table 1- infrastructure expansion for next 25 years – Rio de Janeiro International Airport*
According to ANAC (2013a), the actions proposed in the contract are necessary to assure the permanent development of the Rio de Janeiro International Airport infrastructure until 2038, mitigating the risks of operational bottlenecks during events such as the World Cup (2014) and the Olympic Games (2016), in addition to improving service levels for both customers and civil aviation operators.

**Literature Review**

In a broader sense, according to Yu (2010), DEA-based studies on airport efficiency measurement seek to: evaluate operational efficiencies; illustrate how efficiency measures can be useful for monitoring airport operations; identify characteristics or contextual variables that may explain differences in airport operational efficiency; assess size-impact on efficiency levels; and measure production function slacks. Yu (2010) also identifies two major issues with respect to airport performance measurement: first, the question as to whether or not allowing a reduction or expansion of the capacity level should be adequately answered in order to generate meaningful conclusions for different groups of airports; second, the contextual variables that affect airport efficiency should not be neglected, as policy implementation venues may remain unclear to airport authorities. Great effort has been made during this research to provide insights regarding the first question.

It is interesting to note that, despite one of its major shortcomings (the strong assumption of uniform reduction in all input or uniform increase in all output to achieve higher efficiency levels), the non-parametric DEA frontier model remains widely used in airports efficiency research in general - especially in the last decade, probably because it has been successfully applied to a wide number of different planning situations (Wanke, 2012a). Distance Friction Minimization (DFM), however, is one of the most recent solutions for this major DEA drawback: there is, in principle, an infinite number of improvement paths that a Decision Making Unit (DMU) could take in order to reach the efficient frontier (Golany, 1988). The DFM approach, which was developed by Suzuki et al. (2010), serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. In this approach, a generalized distance function, based on a Euclidean distance metric in weighted spaces, is proposed to assist a DMU in improving its performance by an appropriate movement towards the efficiency frontier surface. Such approach offers a refreshing perspective on efficiency enhancement by employing a weighted projection function. This can address both input reduction and output augmentation options. More recently, Suzuki and Nijkamp (2011) extended the DFM approach to circumstances where decision makers are faced with fixed factors or non-discretionary variables, following the seminal ideas of the Banker and Morey (1986) model.

With regards to the specific Brazilian case, few DEA-based studies have appeared in international peer-review journals. Almost all studies primarily addressed the issues of capacity expansion and the impacts of managerial style on financial and operational performance, leading to similar conclusions. Fernandes and Pacheco (2002), for example, analyzed the efficient use of airport capacity, identifying the input slack in major Brazilian airports. Based on passenger demand forecasts, the authors determined, for each airport, the periods of time when capacity expansions would become necessary to maintain current levels of service. It was found that the great majority of efficient airports, including Guarulhos and Confins, should have had their infrastructure expanded by that time.
Pacheco and Fernandes (2003) analyzed the managerial efficiency of 35 Brazilian domestic airports in both financial and managerial terms. Again, the authors found that the best performing airports, although managerially efficient, were at the limit of their physical capacity, a situation that should have triggered further investments and spending. Some examples given were Confins, Santos Dumont, and Congonhas, among the major airports. Pacheco et al. (2006) investigated managerial style changes impacts on airport performance between 1998 and 2001. The idea was to assess whether or not Brazilian airports had been adequately restructured, both in financial and operational terms, during this three-year period, prior to privatization. Despite the traditional view prevalent in Brazil until very recently (i.e., airports should be kept as purely government-subsidized public facilities), overall evidence suggests a decline in operational performance (due to infrastructure bottlenecks) in parallel with improved financial performance (due to the additional revenues generated from services offered to the general public within the airport environment, such as fast food courts, parking lots, duty-free shops, bookstores etc.).

More recent studies for the Brazilian case include Wanke (2012) and Wanke (2013), where different DEA approaches have been used to assess efficiency related-issues in 63 major Brazilian airports. Starting out with the bootstrapping technique presented in Simar and Wilson (2004), several DEA estimates were generated by Wanke (2012a), allowing the use of confidence intervals and bias correction in central estimates to test for significant differences in efficiency levels, returns-to-scale, and input-decrease/output-increase. Results from this research corroborate previous anecdotal and empirical evidence regarding a capacity shortfall within Brazilian airports, where infrastructure slack is virtually inexistent, regardless of airport type and location. Wanke (2013), in turn, evaluated efficiency in Brazilian airports using a two-stage process (in the first stage, physical infrastructure efficiency was related to the number of landings and take-offs per year and, in the second stage, flight consolidation efficiency was related with the number of passengers carried and cargo handled per year). Results indicate that contextual variables or efficiency drivers, such as hub operations and airport location, impact physical infrastructure and flight consolidation efficiency levels differently.

Methodological fundaments

DEA is a non-parametric model first introduced by Charnes et al. in 1978 (Cooper et al., 2001). It is based on linear programming (LP) and used to address the problem of calculating relative efficiency for a group of DMUs by using multiple input and output measures. Given a set of DMUs, inputs, and outputs, for each DMU the DEA determines a measure of efficiency obtained as a ratio of weighted outputs to weighted inputs.

Several approaches in DEA have been developed to study efficiency in several industries over the last decade. In special, the DFM Approach, originally proposed by Suzuki et al. (2010), is based on the DEA BCC model (Banker et al., 1984) in order to provide an appropriate projection model to improve efficiency in DEA. More precisely, DFM searches for the point on the efficiency frontier that is as close to the DMU’s inputs and outputs vector as possible, based on a generalized distance friction function that serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. A suitable form of multidimensional projection function is given by a Multiple Objective Quadratic Programming (MOQP) model using a Euclidean distance, while it may also address both input reduction and output augmentation (Suzuki et al., 2010). For a complete discussion on the
fairness in the distribution of contributions from the input and the output side to achieve efficiency, readers should follow Suzuki et al. (2010).

On the other hand, discretionary models of data envelopment analysis (DEA) assume that all inputs and outputs can be varied at the discretion of management or other users. In any realistic situation, however, there may be “exogenously fixed” or non-discretionary factors that are beyond the control of a DMU’s management, which also need to be considered (Lotfi and Jahanshahloo, 2007; Ebadi and Shahraki, 2010). Banker and Morey (1986) developed the first model for evaluating DEA efficiency with “exogenously fixed” inputs and outputs in forms like “age of store” in the analysis of a fast-food restaurants network (Ray, 1991; Roggiero, 1996; Roggiero, 1998). Some examples of non-discretionary factors in the DEA literature are the number of competitors in the branches of a restaurant chain, snowfall or other weather conditions in evaluating the efficiency of maintenance units, soil characteristics and topography in different farms, age of facilities in different universities, the populations of wards in evaluating the relative efficiency of public libraries. In logistics applications, such as in airports, capital is frequently treated as a non-discretionary variable over which management has little to no control (Adler et al., 2013).

For the purposes of this paper, the authors have used the version of the DFM model proposed by Suzuki and Nijkamp (2011), in which both input and output fixed factors (FF) are taken into account. Also, to solve the complete set of the equations for this model, Simple Additive Weighting method (SAW (Steuer, 1986; Hwang and Masud, 1979) was used, mostly due to its simplicity.

Data analysis and discussion of results

Secondary data regarding a sample of the 61 largest Brazilian public airports were, therefore, obtained from the statistical database provided by the Infraero website (2013) for the year of 2012. According to Cooper et al. (2007), the number of DMUs is a relevant issue when using DEA as the cornerstone methodology and it should be at least three times higher than the number of inputs and outputs. The sample of 61 DMUs used in this study is comparable in size to similar DEA applications and the relation between number of inputs and outputs and DMUs, as pointed by Cooper et al. (2007), is also respected.

Concerning the input/output variables used, readers should recall that the main aim of the paper is to assess airport infrastructure capacity, as well as airport output-increase potential. In summary, the idea is to diagnose infrastructure constraints in the short and long term, respectively, using fixed factors for some inputs and outputs. The seven inputs collected from each airport are: airport area (m²), apron area (m²), number of runways, total runway length (m), number of aircraft parking places, number of automobile parking places and terminal area (m²). With respect to the outputs, three variables were collected: number of landings and take-offs (per year), number of passengers (per year) and express cargo throughput (kilos per year). These inputs and outputs are amongst the most frequent ones considered in the previous DEA based studies.

The definition on the discretionary/non-discretionary inputs and outputs observed a long/short-term improvement strategy, similarly to what had been proposed by Suzuki and Kijkamp (2011). According to the authors, some inputs or outputs may have a fixed character, implying that they cannot be changed in strategies to improve efficiency. This is an element that has to be taken into account in the efficiency analysis. In the present context, for this research,
only the number of aircraft parking spaces was considered as discretionary variables for input variables. It may be very difficult, especially in short term perspectives, for airport managers to modify infrastructure aspects like airport area, number of runways and terminal area, since such improvements require massive capital investments and detailed studies for demand projection, environmental impacts, future cash flow and so on. However, in some cases, managers have more power to modify this variable using other areas of the airport to perform remote passenger boarding and disembarking. Number of landings and take-offs (per year) and number of passengers (per year) were selected as discretionary output variables for short term perspectives, as a consequence of choosing airport parking spaces as a discretionary variable.

Correlation analyses indicate significant positive relationships between the inputs and the outputs, which are, therefore, isotonic and justified to be included in the model (Marques and Simões, 2010). Descriptive statistics and distribution densities for each input and output are respectively presented in Table 2.

![Table 2 - Summary statistics for the sample (2012)](table2)

Recalling the proposed improvements presented by the concession agreement for the Rio de Janeiro International Airport (ANAC, 2013a, 2013b) in Table 1, one can realize that the contents in this Table can be converted as specific input modifications for this DMU in the initial DEA-DFM model. Moreover, to correctly identify all modifications over time, one possibility is to expand the information regarding this DMU in four more DMUs: Rio de Janeiro International Airport 2016, 2021, 2028 and 2036. The main advantage of this method is that each one of these additional DMUs can be easily inserted in the DFM-DEA model, making the assessment more dynamic and allowing direct comparisons between each additional DMU and the original DMU extracted from Infraero (2013).

Initially, DEA-VRS models were executed five times, i.e., once for database 2012 and for each period of improvements for the Rio de Janeiro International Airport described before (2016, 2021, 2028 and 2036), always keeping 2012 as baseline and replacing the original DMU (Galeão Airport) for a new airport with improvements described by the concession agreement. Among the principal airports in Brazil, Belém, Brasília, Campinas, Congonhas, Confins, Curitiba, Florianópolis, Guarulhos, Galeão, Pampulha, Rio de Janeiro, Salvador, São José dos Campos,
São Paulo, and Vitória were considered efficiently-operating Airports. On the other hand, regional airports like Campina Grande, Ilhéus, Jacarepaguá, Macapá, Maceió, Petrolina, Rio Branco, Santarém and São Luís were considered as Airports of low operational efficiency.

<table>
<thead>
<tr>
<th>Year</th>
<th>Values</th>
<th>%</th>
<th>Values</th>
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<th>Values</th>
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<tbody>
<tr>
<td></td>
<td>Potential for Reducing Number of aircraft parking spaces</td>
<td>Potential for Increasing Number of landings and take-offs</td>
<td>Potential for Increasing Number of passengers</td>
<td>Potential for Reducing Number of aircraft parking spaces</td>
<td>Potential for Increasing Number of landings and take-offs</td>
<td>Potential for Increasing Number of passengers</td>
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<tr>
<td>2012</td>
<td>13</td>
<td>95566</td>
<td>8747868</td>
<td>30.97%</td>
<td>61.93%</td>
<td>50.00%</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
<td>95566</td>
<td>8747868</td>
<td>0.45%</td>
<td>61.93%</td>
<td>50.00%</td>
</tr>
<tr>
<td>2021</td>
<td>0</td>
<td>95566</td>
<td>8747868</td>
<td>0.45%</td>
<td>61.93%</td>
<td>50.00%</td>
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<tr>
<td>2028</td>
<td>12</td>
<td>196725</td>
<td>24029462</td>
<td>11.62%</td>
<td>127.48%</td>
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<tr>
<td>2036</td>
<td>0</td>
<td>196725</td>
<td>24029462</td>
<td>0.45%</td>
<td>127.48%</td>
<td>137.34%</td>
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Then, the DFM model with fixed factors was also executed five times, always replacing the original Galeão Airport DMU for DMUs that correspond to the improvement projections announced by Infraero and ANAC (2013b). Table 3 shows the final results for reducing input and increasing output potentials per year for the Rio de Janeiro International Airport.

At first sight, results from Table 3 show an increase in both potential landing and take-off numbers and passenger traffic over time. As expected, this increase could be understood as direct reflection of the infrastructure improvements announced by ANAC (2013a), since most of the variable inputs for this DMU were modified. However, the results presented by Table 3 only describe operational slacks for the Rio de Janeiro International Airport. To perform a more correct assessment of potential capacity shortfalls in the future, a comparison will have to be made between the total capacity of this airport (and, in this specific case, using operational slack as a proxy to define an airport’s maximum operating capacity without lowering efficiency) and the projected demand for the next 25 years, using data provided by ANAC (2013a, 2013b). This comparison is showed in Figures 1 and 2, where a few in-depth insights are provided for Figures 1 and 2. First, the model used in this paper reveals that there is no expected capacity shortfall for the Rio de Janeiro International Airport until 2016. It means that, when aircraft movement and number of passengers are taken into consideration for this airport, estimated infrastructure improvements due in 2016 are primarily adequate and aligned with the projected demand for the World Cup (Brazil 2014) and the Olympic Games (2016). However, for the period between 2018 and 2028, the announced infrastructure expansion seems to be insufficient, once the projected demand is higher than the total operational capacity for this airport, in both situations (estimated aircraft and passenger movement). This situation represents a potential operational bottleneck in the medium term for the Rio de Janeiro International Airport, where managers and public authorities should pay closer attention to the potential decrease of quality indicators. Even with a large expansion scheduled for completion in 2028, the scenario will be less critical only for a short period, since the expected demand will again be higher than the total capacity from 2032 to 2040.
With possible operational bottlenecks in the medium and long term, this overall picture calls for urgent reallocation of actions announced for the infrastructure expansion presented by ANAC (2013a). One suggestion, for instance, is to anticipate the actions expected to be completed only in 2028, such as the construction of a new passenger terminal, to prevent insufficient capacity in periods after the end of the Olympic Games (Rio 2016) (a sensitive analysis in the studied model showed that modification of the terminal area, apron area and/or aircraft parking spaces has been considered highly effective to increase operational slack). Since others airport expansion programs may face similar issues, the Brazilian Authorities should perform a full review of the chronological sequence of infrastructure investments for major
Brazilian airports, always taking relevant project aspects into consideration, such as future demand, economical perspectives, and public policies.

Conclusions and managerial implications

In this study, a DEA-DFM approach with fixed factors was used to assess a match between expected demand for the next 25 years and the infrastructure expansion investments announced by Infraero and ANAC for the Rio de Janeiro International Airport. The results show evidences that the projected infrastructure expansion will not prevent capacity shortfalls in a medium and long term and, as a result, should lead to a complete review of the chronological sequence of infrastructure improvements planned for 2018.

The contribution of this paper is two-fold. On the theoretical side, the implementation of the new DEA method proposed by Suzuki and Kijkamp (2011) seems to be very promising, especially when the research focuses mainly on operational slacks. Additionally, the managerial implication of measuring these slacks can be used as a basis for establishing future action plans and corporate strategies. For instance, when should a given airport start building a new runway? This may imply different concerns in terms not only of capital investments but also public policies.

The lack of infrastructure investments throughout several decades and the fact that Brazil will host important events such as the World Cup (Brazil 2014) and the Olympic Games (Rio 2016) have fostered the need to carry out studies on the efficiency of Brazilian Airports over the last decade. In this context, this study is a practical contribution for the air transportation sector in Brazil. More precisely, Brazilian Authorities and concessionaire managers may use it general conclusions as guidance to determine the future steps that should be taken to ensure a higher output and improved customer service levels.

A natural extension of this paper would be to compare it with alternative methodologies for slack analysis, like Independent Component Analysis (IDA-DEA) and Principal Component Analysis (PCA-DEA), Slack Based Measure (SBM-DEA) and so on. Thus, these proposed studies would represent a very important factor to develop the DFM-DEA approach with fixed factors as a powerful toolbox to evaluate operational efficiency, since this methodology is present in only a few studies. Further research should also explore a broader dataset of airports, including foreign airports from North and Latin America, Europe, Asia and Africa.

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References


