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Performance Efficiency Measurement of Airports:

A Comparative Analysis of Airports Authority of India and Public Private Partnership

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ABSTRACT

This article describes how to improve the overall efficiency and effectiveness of the aviation sector and also to source extra funding, the Government of India has paved the way for private investors through to a Public Private Partnership (PPP) model since the 1980s. This liberalization step in the Indian aviation market has minimized the institutional barriers which have hindered the freedom and flexibility of air transport operations among private investors. Now, competition within the aviation sector has become fiercer; the Airports Authority of India (AAI) and Public Private Partnership (PPP) in Indian airports are not only providing varied services, but also attracting consumers with new infrastructure and full modern facilities. The importance of this article is because after privatization, no studies have been conducted to examine the efficiency of Indian airports by using Data Envelopment Analysis (DEA). An output-oriented DEA model is employed to determine the efficiency score of airports by taking a sample of 15 airports, including airports run by PPP, for comparison. Output-oriented DEA calculates the efficiency by maximizing the outputs for a given level of inputs. Therefore, this article contributes to the existing literature on Indian airports. Based on available data, three variables - length of runways, terminal size and number of check-in counters, are used as inputs and two variables - passenger movement and aircraft movement, are used as outputs.

KEYWORDS

Data Envelopment Analysis (DEA), Efficiency, Privatization, Public Private Partnership (PPP)

INTRODUCTION

The transport sector is seen as the lifeline of an economy (Koçak, 2011). To a large extent, the growth and development of an economy is dependent on the growth of the transport sector. The transport sector consists of road, railways, ports and airports. The airport sector is considered as one of the essential elements of the transport sector, as growth of the airport sector is crucial for the overall growth of the transport sector and the Indian economy. Modern and full-facility airports can help

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India to move forward as one of the most powerful economies of the world (Kumar et al., 2017a; Kumar et al., 2017b). Airports and airlines have historically been considered as vital components of the national aviation system, and therefore both are regarded as public utilities. An earlier traditional airport management model was more prevalent but governments realized that it is an unsustainable model in the long run because of inefficiency and the burden of financing airports. Since the 1980s, airports have been privatized in an effort to become more efficient and to allow governments to use funding in other ways. Currently, the government regards airports as potential profit-making enterprises instead of just considering them as suppliers of infrastructure.

Airport Infrastructure in India

Earlier Indian airports were administered by the Civil Aviation Department, Government of India, till the creation of the International Airports Authority of India (IAAI) in 1972 and subsequently the National Airports Authority (NAA) in 1986. Airports Authority of India (AAI) was constituted by an Act of Parliament on 1st April 1995. It came into being by merging the erstwhile National Airports Authority and the International Airports Authority of India. Through the merger, a distinct organization evolved being responsible for creating, improving, maintaining and supervising civil aviation infrastructure (Airport Authority of India). AAI manages 125 airports, which include 11 International Airports, 8 Customs Airports, 81 Domestic Airports and 27 Civil Enclaves at Defence airfields. The report quoted from AAI (Airport Authority of India) on traffic trends at all airports of AAI shows that in the years 2002-2003, 2003-2004 and 2004-2005 passenger traffic increased by 9.35%, 11.56% and 21.5% respectively. Similarly, there was also rapid growth in freight and aircraft traffic. Cargo traffic grew by 14.64%, 9.1% and 19.8% while aircraft movement increased by 9.9%, 14.4% and 11.88% respectively.

According to the report of the Investment Commission (Investment Strategy for India, 2006), the encouraging statistics on the trend of human population and rapid growth in the economy points to a continued expansion in domestic passenger traffic and international outward traffic. The rise in traffic and cargo movement leads to over-crowding situations at different airports in India. This is apparent in Chennai, Delhi, Bangalore, Hyderabad, Kolkata and Mumbai. That’s why the country requires modernization of metro airports, development of new airports, generation of technology for efficient treatment of passengers, cargo and better practices in management.

Public Private Partnership in Indian Airports

Since the revenue generated by AAI was found to be inadequate to satisfy spending requirements, public private partnership became essential to bridge the funding gap. Public Private Partnership (PPP) projects deliver an infrastructure service which is based on a long-term contract between government or legal entity on one side and a private sector company on the other. It is particularly targeted towards financing, designing, implementing and operating infrastructure facilities and services in the State. The aim of PPPs is to achieve the objectives of both high growth and equity on a sustainable basis. Through PPPs, a large number of projects have been accelerated to meet the deficit in investments; thus, it is an essential tool. The critical link between infrastructure facilities and economic growth was realized from the First Five Year Plan onwards with outcomes given a high priority and more emphasis placed on the development of infrastructure. The Industrial Policy Resolution of 1956 reserved infrastructure solely for the public sector and as a result, the Government of India took on the responsibility for the development of infrastructure. If the overall infrastructure development is fully analyzed, it can be seen that development was lacking till the beginning of the 1990s; the reason for this was the scarcity of resources. The liberalization of the economy introduced by the government in 1991 placed special emphasis on the development of infrastructure as there was recognition that if India was to emerge as a strong nation, then infrastructure standards should match international levels. Infrastructure covers investments in roads, highways, airports, ports and railways.

PPP addresses the problems of insufficient ground handling systems, obsolete infrastructure, night landing facilities and poor passenger services. Other objectives which private participation has targeted are building airports to be more user-friendly thus achieving a higher level of customer gratification, building world class airports equipped with modern technology and better management practices, focusing on infrastructure development in remote areas, anticipating demand and building airport capacity accordingly and greater competence in airport operations. According to the report by the Planning Commission (Financing Plan for airports, 2006) metro airports at Delhi, Mumbai, Bangalore, Hyderabad, Chennai and Kolkata are to be developed through PPP. The major projects (Position paper on the airports sector in India, 2009) developed through PPP are:

- Cochin International Airport is the first airport in India set up under a PPP model. The airport came about as a model enterprise with equity participation from the Government of Kerala, industrialists, financial institutions, airport service providers, NRIs and the public (Cochin International Airport Ltd., 2007) with a total spend of about Rs 283 crore, occupying approximately 1300 acres of land. It has been constructed in such a way that any type of large bodied aircraft can easily take off and land. The airport is situated so that three national highways which pass through Kerala are easily accessible. The airport was built in phases to accommodate investment streams and to generate profit at the earliest opportunity;
- Bangalore International Airport was built under a PPP model. The equity participation from the consortium of companies such as Larsen and Toubro, Siemens and Zurich Airport is 74% while the AAI holds the remaining 26%. The concession agreement between the Government of India and Bangalore International Airport. Limited (BIAL) was signed in July 2004. BIAL has exclusive rights to carry out the development, design, financing, construction, management and operation of the airport for a period of 30 years from its opening date, with an option to extend the concession for another 40 years (Bengaluru International Airport, 2010). Airport area is approximately 4000 acres. The initial phase of airport development was completed in March 2008. Just one phase of the master plan is complete and there is ample expansion scope. The airport has a runway length of 4000m which is 60 m wide and has three rapid exits which lead aircraft to leave the runway just after landing. In this way there is optimum use of the runway;
- Hyderabad International Airport: The association of GMR Infrastructure Limited and Malaysia Airports Holdings Berhad was chosen to develop Greenfield International Airport at Shamshabad near Hyderabad. The GMR group holds 63% of the equity, Malaysia Airports Holdings Berhad 11% while the Government of Andhra Pradesh and AAI hold 13% each. The project is prepared on a Build, Own, Operate and Transfer basis (Hyderabad Rajiv Gandhi International Airport, 2013). The airport area is approximately 5400 acres. The airport has world class facilities and infrastructure. It is made in accordance with ICAO standards. It has the capacity to handle large aircraft; other facilities include self-check in counters, CUTE systems and modern IT systems. The total cost of the project is Rs 2,370 crore;
- Mumbai International Airport is an associate of GVK Industries Ltd and Airports Company South Africa, assigned with the task of developing the existing Mumbai Airport in February 2006. The equity participation of the GVK led consortium is 74% with AAI holding 26%. The airport currently has three domestic and two international terminals. MIAL is now implementing a master plan to build an integrated terminal. After modernization, the new integrated terminal will be referred to as T2 and will be able to accommodate 40 million passengers per annum;
- Delhi International Airport is one of the major international airports from the public private partnership initiative. It is a joint venture of AAI, Fraport, Eraman Malaysia and GMR Infrastructure, tasked with modernizing the airport. DIAL entered into an Operations, Management and Development Agreement (OMDA) on April 4, 2006 with the AAI (Delhi Indira Gandhi International Airport, 2013). The initial term of the concession is 30 years which can be further extended by another 30 years. The development of the new domestic departure

terminal 1D (T1D) was completed on 26th February, 2009. This terminal has seen an increase in the capacity of domestic departures to 10 million passengers per annum. Terminal 3, opened in March 2010, is a state-of-the-art integrated terminal with capacity to accommodate 60 million passengers per annum. It has other salient features such as an area of 5.4 million square feet, 95 immigration counters, over 20,000 square metres of retail space and a record 78 aerobridges. This formed the first phase of the airport development. With an increase in traffic and passenger demand, more terminals and runways will be added in which a U shaped building will be developed in a modular manner.

Much investment has been made by the government to develop the infrastructure since the status of physical infrastructure clearly affects a country's yield, competitiveness in global markets and power to draw foreign investments. But investments in infrastructure require a huge amount of funds due to the large sums of money involved; hence it is desirable to combine the skills, proficiency and experience of both the public and private sectors. Since the 1990s there has been a speedy growth of PPPs around the world. PPP represents a win-win situation as the government earns revenue by renting state-owned assets or instead pays the private sector for improved infrastructure and better delivery of service; often the private sector, by use of its skills and expertise, can do the job more effectively and efficiently and can thus lower prices. The private operator aims for payback for expenses incurred either by government or consumers for doing its work, at a profit. But, there are several problems with PPP as well as limitations and challenges to be faced. There have been many cases of failure of projects due to cost-overrun, time-overrun and unacceptable quality of outcome. Therefore, it becomes increasingly important to look into the impact and effectiveness of the projects undertaken through the PPP model to determine the extent of success. As for the current status of PPP, the number of projects in the airport sector comprises just 1% of the total projects. This sector has a lot of potential for growth as consumers demand airports with excellent and modern facilities; this growth leads to the betterment of the economy. No discussion is available in existing literature about measuring the comparison efficiency of Indian airports. Therefore, this study is an attempt to plug this gap with DEA techniques used to compare the efficiency of privatized airports with airports under AAI.

The rest of this study is organized as follows. In section 2, previous related studies have been reviewed. In section 3, methodology is presented. In section 4, analysis and discussion are explained. In section 5, the research findings are discussed with managerial/practical implications drawn up.

LITERATURE REVIEW

The literature review of this study is divided into two parts 1) public private partnership studies, and 2) airport efficiency studies. A description of these studies follows.

Public Private Partnership Studies

Pillai (2008) identifies the importance of efficient and high-quality infrastructure for balanced development of the Indian economy. Its findings are till June 2006 when 837 projects were complete. The total expenditure incurred for these projects was above Rs.20 cr and the total estimated investment amounted to Rs. 369499 cr. These investments were spread across 16 strategically important sectors of the Indian economy. According to this study there has been a significant decline in the cost overrun of various projects, indicating improved implemental efficiency of the projects.

Manzoor (2010) discusses the importance, challenges and criticisms regarding Indian airports. He concludes that since there was a huge growth in traffic (both passenger and cargo), the government felt it necessary to develop airport infrastructure. In 2007, Mumbai and Delhi handled 25.2 million and 23.3 million passengers respectively. In 2006 these airports were ranked as the world's 55th and 61st busiest airports. To create infrastructure to handle such traffic, the government, lacking in funds, opted for PPP. Many of the Indian airports face serious infrastructure constraints. Some of these constraints are poorly maintained runways, lack of Instrument Landing Systems, runways not suitable to accommodate the world's largest aircraft, e.g. the super jumbo airbus A-380 and lack of night landing facilities. Hence, efficiency is the most common and important motivation to privatize the airports. Another major problem is poor connectivity to the airports. Privatization can help in providing funds to address this. Other benefits of privatization are expanding the operation of duty-free shops, creating more revenue and jobs and providing efficient cargo facilities. The criticisms highlighted are that privatization will lead to 40% jobless and higher unemployment, it will hurt national security and AAI will lose its importance. Supporters' views on airport privatization are that modern airport infrastructure will lead to better performance of the Indian economy, increased operating efficiency, development in the tourism industry, recruitment of qualified and talented employees and provision of greater customer satisfaction.

Ohri (2009) gives the justification for airport privatization in India, drawing from international experience, with a focus on the developing countries. The gaps between Indian and international airports is calculated by using a range of operating and financial metrics to identify possible areas for improvement. The report compared the Unique Zurich group, Brussels airport, Vienna, Indian airports and the British Airport Authority on various operating and financial figures (2004-2005) on three broad factors. These factors are 1) Revenue based factors which include figures such as total revenue per passenger, total revenue per employee etc. 2) Profit based factors which include operating profit per passenger, return on capital employed etc. and 3) Input-output based factors such as total cost per air transport movement, staff cost per passenger, staff cost per employee etc. The report found that Indian airports have a high percentage of aeronautical revenue, low commercial revenue per passenger, very low revenue per employee, low operating profit per passenger, low staff cost per employee and a high percentage of staff cost in the total cost. The report concluded that workforce rationalization and increasing contribution of non-aeronautical revenue are the two major developments for the business models of Indian airports to focus on.

There are a number of studies from Juan (2005) and Button (2006) supporting the fact that carefully designed concession contracts and building appropriate controls are essential for effective privatization. But in the case of bidding processes of both Delhi and Mumbai, the process itself was questioned at various levels. Pandey et al. (2010) identified the problems faced in the bidding processes of Delhi and Mumbai airports. An original completion date of September 2004 was missed due to a variety of reasons; the process was then postponed with final bids received by September 2005. After taking advice from experts, the final decision was made in January 2006 by the empowered group of ministers. Ministers compromised on some of their own set of parameters. One of the losing bidders (Reliance) had appealed to the High Court against the decision of the selection of joint venture partners. The High Court dismissed the appeal and the airport privatization efforts continued. Therefore, it is concluded that there are various factors on which the efficiency of airport privatization depends.

Airport Efficiency Studies

There are several studies which focus on determining airport efficiency. There are only a few studies on airport efficiency before 2000; these include Parker (1999) and Gillen and Lall (1997). Most of the studies on airport efficiency have been conducted after 2000. This indicates that this area of study has become more popular in recent decades. This may be due to increased competition, increased pressure of traffic and privatization of airports. There are various methods to determine airport efficiency such as Partial Factor Productivity (PFP), Total Factor Productivity (TFP), Stochastic Frontier Analysis (SFA) and DEA (Data Envelopment Analysis).

Partial Factor Productivity deals with the ratio of one output to the ratio of another input (Oum et al., 2004). This technique is simple to use but the drawback is that it does not give any idea about overall efficiency. The most common used outputs in PFA technique are the number of passengers, ATMs and cargo movements. PFA focuses on labor, capital and financial productivity. Total Factor Productivity estimates the overall efficiency of airports. This technique weights inputs and outputs according to their importance in production function and builds up an index for the end result. Stochastic Frontier Analysis is a parametric technique which calculates the relative efficiencies of airports. But the drawback with this technique is that it requires a production function of an airport to construct a production frontier. On the other hand DEA does not require the specification of a production or cost function to estimate the production frontier. This is the reason why DEA is the most widely accepted technique for determining airport efficiency.

Different research studies have used different methods and models to determine airport efficiencies. Parker (1999) used DEA-CCR and BCC models to determine the performance of British Airport Authority before and after privatization. The study used inputs such as number of employees, operating cost and capital input and outputs such as number of passengers, turnover and cargo. It analyzed the changes in technical efficiency of BAA over time from 1979/80 to 1995/96. The results showed that there was no significant improvement in efficiency of BAA over this period. Some research papers determined airport efficiency in segments (Pels et al., 2003; Gillen and Lall, 1997). For each segment of study, these researchers have used different inputs and outputs. In 1997, Gillen and Lall used two segments to determine airport efficiency; these are terminal services and movement model. For the terminal services segments, the number of runways, number of gates and terminal area were used as inputs; outputs were number of passengers and cargo. The movement model used number of runways, runway area, airport area and number of employees as inputs; outputs were air cargo movements. An output-oriented method was used to determine the changes in efficiency of airports. Heri Bezić (2010) analyzed the overall efficiency of Croatian airports over a five year period from 2004 to 2008. The study used inputs such as operating cost and number of employees; output was total revenue. This revealed that only two airports were efficient performers when compared to the other airports.

Sarkis (2000) assessed the operational efficiencies of 44 major U.S. airports. The input measures taken for study were number of airport employees, airport operational costs, gates and runways; output measures include passenger flow, operational revenue, commercial and general aviation movement and total cargo transportation. The results of the study show that overall mean efficiency of major US airports increased through the years from 1990 to 1994 with a small drop recorded in 1993.

Koçak (2011) determined the efficiency of Turkish airports for the year 2008 by using a DEA approach. The input variables taken are operational expenses, number of personnel, flight traffic and number of passengers; output variables are number of passengers/area, flight traffic/runway, total load and operational revenue. It uses both CCR and BCC models to determine efficiency. Out of 40 airports, only 7 airports are found to be efficient. There are several other studies which have used different inputs and outputs based on the availability of data. In a study by Pels et al. (2003) to determine the efficiency of European airports, both DEA and SFA methods have been used. According to his study, both methods showed roughly the same results. Numerous research papers in this area show that determining airport efficiency is important and that DEA is a widely accepted technique for this.

METHODOLOGY

Data Description

In this study, 15 international airports are taken to ensure comparison of efficiency. The 15 airports include 5 privatized airports; these are Delhi, Bangalore, Hyderabad, Nagpur and Cochin. 10 are AAI airports. The input data of AAI airports is taken mostly from the Airport Authority of India database while the input data of privatized airports is taken from various relevant sources. The output data of all the airports is obtained from the AAI database. Based on the availability of data, three variables are taken as inputs - length of runways, terminal area and number of check-in counters (including common-use self-service kiosks). The output variables are comprised of two variables - total passenger movements and total aircraft movements. The input data has been obtained from various sources for the year 2012 and the output data recorded for the period April 2011 to March 2012. Table 1 displays the data obtained.

As the study is concerned with the use of DEA to determine the technical efficiency of airports, a detailed description of the technique is discussed.

Data Envelopment Analysis (DEA)

In literature, Data Envelopment Analysis is defined as a tool to measure efficiency for non-parametric frontier-efficiency (Charnes et al. 1978). For homogenous entities, DEA determines the relative efficiency of a set of DMUs. Cooper et al. (2011) defined relative efficiency. "DMU is to be rated as fully (100%) efficient on the basis of available evidence if and only if the performances of other DMUs does not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs." It is noted that this definition does not mention any kind of assumptions such as the requirement of weights or any kind of relation that exists between inputs and outputs. This basic efficiency is termed as "technical efficiency" (Du and Sim, 2016). This efficiency can be extended to other areas such as allocative efficiency and economic efficiency, when data related to unit cost, price, etc. is available. DEA analyzes the efficiency of a DMU by comparing it with the best DMU in the group of units under consideration.

The basic idea in DEA is to develop the "best practice" production frontier (Du and Sim, 2016). With reference to this frontier, the position of inefficient units is determined and also the source and amount of inefficiency can be identified. DEA is an important productivity analysis tool that is extensively applied in the case of manufacturing and service operations to evaluate their performance. Since this technique requires very few assumptions, it can be applied in those contexts where other

Table 1. Data of international airports in India

Name of Airports	Inputs			Outputs	
	Length of Runways (m)	Terminal Size (sq.m.)	Counters Checkin	Passenger Movements	Aircraft Movements
Delhi	11053	536676	256	35881965	295491
Bangalore	4000	73347	71	12698343	118431
Hyderabad	7967	105000	146	8444431	99013
Nagpur	5138	17500	20	1415739	15322
Kolkata	6466	65355	94	10303991	99843
Chennai	5690	62120	93	12925218	120127
Amritsar	3658	4000	30	892104	9208
Jaipur	2797	22709	16	1828304	18603
Ahmedabad	3505	70423	62	4695115	40506
Guwahati	2743	8655	14	2244684	28088
Trichy	2480	11700	12	908771	9583
Calicut	2860	118981	35	2209716	16150
Thiruvananthpuram	3398	45863	48	2814799	27239
Goa	3480	15897	37	3521551	27430
Cochin	3400	53698	27	4717650	40181

techniques can't operate because of the complexities involved in them. In 1957, Farrell extended the concept of productivity and introduced the concept of "efficiency". Based on Farrell's work, in 1978, Charnes et al. proposed the initial model of DEA known as the CCR model with assumption an input orientation and assumed constant returns to scale (CRS).

CCR and VRS DEA MODEL

According to the study by Talluri (2000) the efficiency score in the presence of multiple input-outputs can be defined as:

$$\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} \tag{1}$$

Assume that there are n DMUs to be evaluated. Each DMU has m inputs and outputs. The relative efficiency of a test DMU p can be obtained by the model proposed by Charnes et al. (1978):

$$\max \frac{\sum_{k=1}^{s} u_k y_{kp}}{\sum_{j=1}^{m} v_j x_{jp}}$$

$$s.t \quad \frac{\sum_{k=1}^{s} u_k y_{ki}}{\sum_{j=1}^{m} v_j x_{ji}} \leq 1 \ \ \forall i \tag{2}$$

$u_k v_j \geq 0 \ \ \forall k, j$, where $i = 1 \ldots\ldots$ n

y_{ki} = amount of output k produced by DMU_i

x_{ji} = amount of input j consumed by DMU_i

u_k, v_j = weight given to output k and input j, respectively

The above maximization problem can have an infinite number of solutions. If u^*, v^* are solutions to this problem then it can be shown that any $\theta, \theta u^*$ and θv^* are also solutions to the same problem. Hence θ cannot be identified. So, in order to avoid this problem, it has been converted from a fractional program into a linear programming equivalent:

$$\max \sum_{k=1}^{s} \mu_k y_{kp}$$

$$s.t \quad \sum_{j=1}^{m} v_j x_{jp} = 1$$

$$\sum_{k=1}^{s} \mu_k y_{ki} - \sum_{j=1}^{m} v_j x_{jp} \leq 0 \forall i$$

$$\mu_k v_j \geq 0 \ \forall \ k, j$$

The above form is known as multiplier form of a linear programming problem. The problem is run n times, one linear programming problem for each DMU. Each DMU selects its input and output weights so that its efficiency score is maximized. According to the study by Charnes et al. (1978), DEA assigns a score of 1 or less than 1. A score of 1 means that when the DMU is compared with the other units in the sample there is no indication of inefficiency in any input or output. A score of less than 1 means that the DMU is relatively inefficient i.e. a linear combination of other units under consideration can produce the same output vector by using a smaller input vector. Using the duality in linear programming, the equivalent envelopment form of this problem is:

$$\min \theta$$

$$s.t \sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jp} \leq 0 \forall j$$
$$\sum_{i=1}^{n} \lambda_i y_{ki} - \theta y_{kp} \leq 0 \forall k \tag{4}$$

$$\lambda_i \geq 0 \quad \forall i$$

where θ is the efficiency score and λ = dual variables.

The duality form has less constraint than the multiplier form and hence it is a preferred method to use. Coelli (1996) has simplified the duality form by taking the inputs and outputs in vector form. Assuming that there is data on K inputs and M outputs on each of N DMUs, then for the i-th DMU the input and output are represented by vectors. The input matrix X (K×N) and the output matrix Y (M×N) represent the data of all N DMUs. Then the envelopment form is:

$$\min_{\theta,\lambda} \theta$$

$$s.t \; -y_i + \lambda Y \geq 0$$

$$\theta x_i - X\lambda \geq 0 \tag{5}$$

$$\Lambda \geq 0$$

where λ is a N×1 vector of constants and θ is scalar. Θ will give the efficiency score of the i-th DMU.

The above envelopment and multiplier models are input-oriented i.e. how much input can be proportionally reduced without altering the output quantity. In the case where the DMUs have less control over the output side, input-oriented models are used. As opposed to the input-oriented models, output-oriented models exist which determine by how much the output quantities can be proportionally expanded without altering the input consumed. It may be used in cases where DMUs are given a fixed quantity of resources and they need to produce as much output as possible. The output oriented envelopment model is (Cooper et al., 2011) where m represents a number of inputs, s a number of outputs and *n* the number of DMUs. Then the efficiency of DMUo can be determined considering DMU_j consumes x_{ij} of input i and produces y_{rj} of output r:

max Φ

subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} - x_{io} \leq 0$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} - \phi y_{ro \geq 0} \qquad (6)$$
$$\Lambda_j \geq 0$$

where *i* varies from 1 to *m, r* from 1 to *s, j* from 1 to n.

Multiplier form of output-oriented model is:

$$\min q = \sum_{i=1}^{m} u_i x_{io}$$

subject to:

$$\sum_{i=1}^{m} v_j x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} \geq 0$$
$$\sum_{r=1}^{s} \mu_r y_{ro} = 1$$

$$\mu_r v_i > 0 \ \forall r, i \qquad (7)$$

Therefore, based on which quantity the managers have more control over, the appropriate orientation can be selected. Figure 1 and 2 show the technical efficiency from input orientation and output orientation respectively. Figure 1 shows an illustration by Farrell (1957) using a simple example involving two firms using inputs x1 and x2 to produce a single output y. SS´ represents the efficiency frontier. Since DMU Q lies on the frontier, this means that its efficiency score is 1. On the other hand, the firm P is inefficient since it lies above the frontier. The distance QP represents

Figure 1. Technical efficiency from input-orientation (Coelli, 1996)

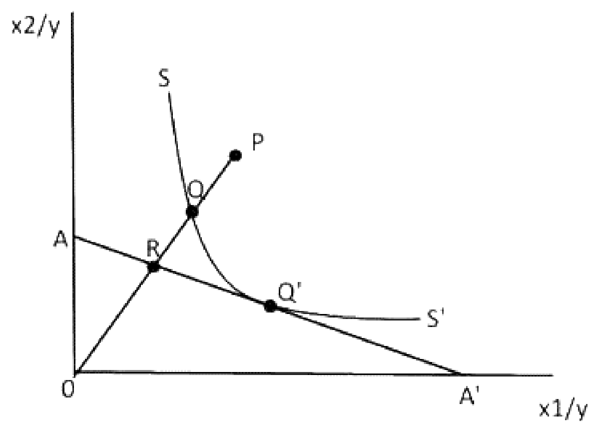
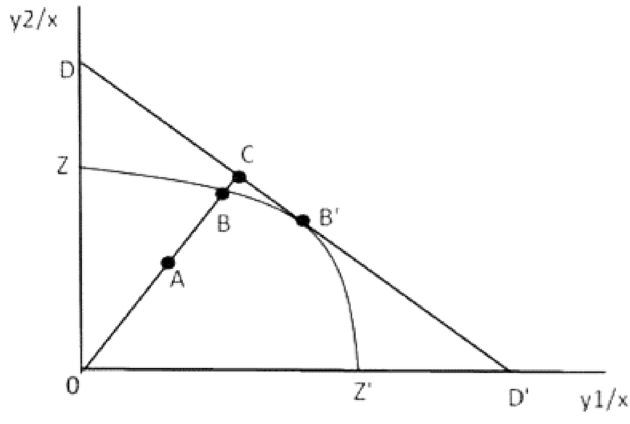


Figure 2. Technical efficiency from output orientation (Coelli, 1996)



the technical inefficiency of the firm. The ratio QP/OP represents the percentage by which all inputs could be reduced. The technical efficiency of the firm is defined as OQ/OP.

Similar to the above case the output-oriented measure can be illustrated by taking the case where the firm produces two outputs y1 and y2 and consumes one input x1. The curve ZZ´ represents the efficient frontier i.e. the upper boundary of production possibilities. Since the DMU B lies on it, it is technically efficient and has an efficiency score of 1. DMU A lies below the curve; hence it is inefficient. The technical inefficiency of DMU A is represented by distance AB. Hence the output oriented technical efficiency for DMU A is OA/OB. The input-oriented and output-oriented measures will give an equivalent technical efficiency score in the case of constant returns to scale but they will be unequal when increasing or decreasing return to scale exists. If the constraint (8) (Coelli, 1996) is added then it is known as the BCC model after Banker et al. (1984). VRS and CRS DEA operate on the same data. If there is a difference between the two scores this means that the DMU is not operating at optimal scale:

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{8}$$

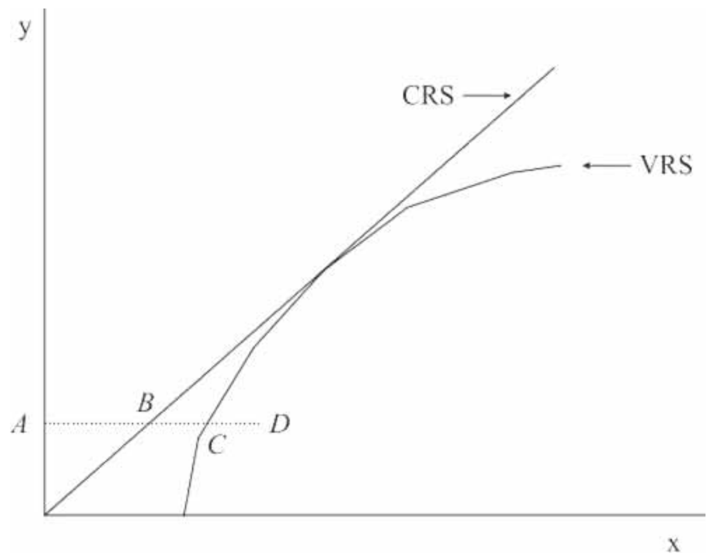
CRS model efficiency score is further broken down to scale efficiency and pure technical efficiency:

$$E_{CCR} = E_{SCALE} * E_{BCC} \tag{9}$$

Figure 3 (Pels et al., 2003) shows both the production frontiers VRS and CRS. The technical efficiency score for the point D under CRS is AB/AD, while the technical efficiency score under VRS is AC/AD. The efficiency score under VRS is always greater than or equal to the CRS score because VRS forms a convex hull of intersecting planes which envelope the data more tightly. The scale efficiency is ECCR/EBCC. So, scale efficiency score is AB/AD. The drawback with this measure of scale efficiency is that it does not indicate whether the DMU is operating at an increasing return to scale or a decreasing return to scale. To determine this, constraint (8) is changed to:

$$\sum_{j=1}^{n} \lambda_j \leq 1$$

Figure 3. Production frontier



If the score obtained by adding this constraint is the same as the VRS technical efficiency score, then decreasing returns to scale exist and if they are unequal then increasing returns to scale exist. CRS assumes that increase in inputs lead to proportionate increase in outputs. This means that in whichever scale the unit operates, its efficiency will not change. But in the case of VRS, increasing or decreasing returns to scale exist. Increasing returns to scale mean that an increase in unit input leads to greater than proportionate increase in its outputs while decreasing returns to scale mean that an increase in unit input leads to lower than proportionate increase in outputs.

ANALYSIS AND DISCUSSION

An output-oriented DEA model is used for determining the efficiency score of airports. Output-oriented DEA calculates the efficiency by maximizing the outputs for a given level of inputs. In the case of airports, factors of production are fixed or semi-fixed; an output-oriented model shows how intensively airport resources can be utilized. Also, it is not easy for managers to disinvest once capital is dedicated to constructing new runways, terminals and other infrastructure. It is assumed that the DMUs operate at optimal scale so the CRS model is used. In order to compute efficiency scores, the DEAP Version 2.1 computer program is used. Table 2 shows the results obtained from the program.

CRS scores can be further broken down into VRS efficiency and scale efficiency. The results obtained by applying the VRS model are shown in Table 3. In the case of the VRS model, efficiency score rises as in this case, airports of similar size are compared with each other and not with the best ones in the sample taken.

It is noted that in the case of the BCC model 7 out of 15 airports have relative efficiency score of 1. These 7 airports are made up of 3 privatized airports - Delhi, Bangalore and Cochin and 4 AAI airports - Chennai, Amritsar, Guwahati and Trichy. In the case of privatized airports, the lowest efficiency score is at Nagpur i.e. 0.422. This means it is 42.2% efficient when compared to the airports with an efficiency score of 1. Public airports efficiency (except airports having efficiency score 1) varies from 0.362 to 0.954. The lowest efficient AAI airport is Thiruvananthapuram according to the results. It is found that 8 airports are operating at increasing returns to scale, 3 with decreasing returns to scale and 4 of constant returns to scale. Scale efficiency varies from 0.442 to 1. In the case

Table 2. Efficiency scores under CRS model

Airports	CRS Efficiency Score
Delhi	1
Bangalore	1
Hyderabad	0.524
Nagpur	0.417
Kolkata	0.778
Chennai	1
Amritsar	0.86
Jaipur	0.659
Ahmedabad	0.423
Guwahati	1
Trichy	0.442
Calicut	0.353
Thiruvananthpuram	0.341
Goa	0.931
Cochin	0.977

Table 3. Efficiency scores under VRS model

Airports	CRS_{te}	VRS_{te}	Scale	
Delhi	1	1	1	-
Bangalore	1	1	1	-
Hyderabad	0.524	0.728	0.720	drs
Nagpur	0.417	0.422	0.988	irs
Kolkata	0.778	0.823	0.945	drs
Chennai	1	1	1	-
Amritsar	0.860	1	0.860	irs
Jaipur	0.659	0.699	0.942	irs
Ahmedabad	0.423	0.53	0.799	irs
Guwahati	1	1	1	-
Trichy	0.442	1	0.442	irs
Calicut	0.353	0.573	0.616	irs
Thiruvananthapuram	0.341	0.362	0.942	irs
Goa	0.931	0.954	0.980	drs
Cochin	0.977	1	0.977	irs

te = technical efficiency

of Trichy airport, the inefficiency is due to scale only. The average efficiency score in privatized airports is 0.83 while in AAI airports it is 0.79 i.e. a gap of around 4%. This shows that privatized airports on average are better in efficiency when compared to public airports.

Table 4 illustrates the summary of output targets and input targets for each airport. It shows the targets to be achieved so that the airports can operate at an efficiency score of 1. Thus, for example Hyderabad could have achieved the output target of passenger movement of passenger movements of approximately 14999547.081 and aircraft movement of 135972 by reducing the inputs i.e. length of runway to 6174m. Table 4 shows the peers for each airport. The number of times an airport acts as peer helps in identifying the best practices within the sector. Peers identify the set of efficient airports which make up the appropriate frontier for a given airport. Airports which are technically efficient don't have other airports as peers while inefficient airports have a benchmark which is composed by other DMUs. A peer can be identified as more or less important based on the weight assigned to it in the BCC model which is expressed by "lambda (λ)". It is seen that Bangalore appears 6 times as a target for the rest of the airports and hence can be considered as a benchmark. Managers of less efficient airports should improve their performance by learning from the experiences of those airports which are doing better - Bangalore, Guwahati, Delhi, Chennai and Cochin.

The technical efficiency score obtained shows that four out of 15 airports are efficient airports, having maximum efficiency value of 1. This means that these airports could neither increase their output without increasing their inputs nor reduce their inputs without reducing the output. These four airports comprise two privatized airports - Delhi and Bangalore and two public airports - Chennai and Guwahati. This shows that out of five privatized airports, two airports have efficiency 1, while in the case of public airports two airports have efficiency 1 out of a total of 11 airports. The technical efficiency of other public airports varies in the range

Table 4. Summary of airports with peers

Airport	PEERS With Optimal Lamdas (λ)					
Delhi	1	Delhi				
Bangalore	1	Bangalore				
Hyderabad	0.91	Chennai	0.09	Delhi		
Nagpur	0.843	Guwahati	0.067	Cochin	0.09	Bangalore
Kolkata	0.004	Bangalore	0.007	Delhi	0.989	Chennai
Chennai	1	Chennai				
Amritsar	1	Amritsar				
Jaipur	0.027	Cochin	0.944	Guwahati	0.029	Bangalore
Ahmedabad	0.674	Bangalore	0.326	Trichy		
Guwahati	1					
Tiruchirapalli	1					
Calicut	0.75	Trichy	0.25	Bangalore		
Thiruvananthapuram	0.224	Guwahati	0.565	Bangalore	0.211	Trichy
Goa	0.865	Guwahati	0.135	Chennai		
Cochin	1	Cochin				

from 0.34 to 0.97. Of the major airports i.e. Delhi, Bangalore, Hyderabad, Kolkata, Chennai and Cochin-Delhi, Bangalore and Chennai are found to be relatively efficient with an efficiency score of 1 while Cochin and Kolkata have high relative efficiency scores when compared with Hyderabad. The mean efficiency score under the CRS model is 0.714. The average efficiency scores in private airports is 0.788 while in public airports, the score is 0.678. The gap is around 11%. Comparative efficiency scores are also shown in Figure 4.

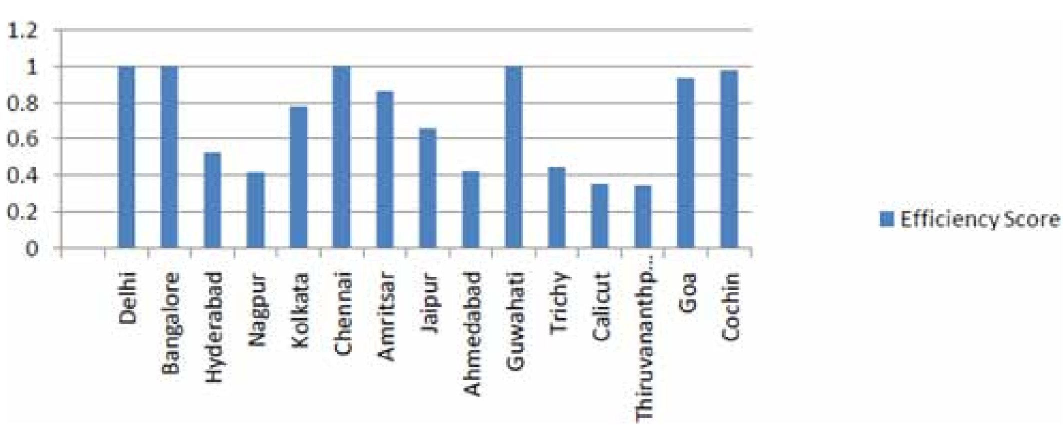
THEORETICAL AND MANAGERIAL IMPLICATIONS

There have been research works in the past which deal with assessing worldwide airport efficiency. This research deals primarily with applying Data Envelopment Analysis to assess the efficiency of Indian international airports by taking a sample of 15 airports. Since some of the major international airports such as Delhi, Bangalore, Hyderabad, Cochin and Mumbai are being developed through public private partnership, the study aims to find out whether airports operating under PPP are relatively more efficient when compared to the airports managed by the Airport Authority of India. To determine the relative efficiency score a non-parametric, linear programming based DEA technique is utilized. An output-oriented CCR model is used to estimate the efficiency of 15 Indian airports for the year 2011-2012.

None of the recent research works have used DEA to analyze the efficiency of Indian airports after privatization. Therefore, this study is useful in contributing to the existing literature on Indian airports. Based on the available data three variables (input) - length of runways, terminal size and number of check-in counters - are used as inputs and two variables (output) - passenger movements and aircraft movements - are used as outputs. The results of the DEA show that of the five privatized airports taken for the studyi.e. Delhi, Bangalore, Hyderabad, Cochin and Nagpur, the efficiency score of three airports -Delhi Bangalore and Cochin is found to be 1; in the case of public airports, the efficiency of Chennai, Amritsar, Guwahati and Trichy is found to be 1. The average efficiency score in privatized airports is 0.83 while in AAI airports it is 0.79 i.e. a gap of around 4%. This shows that privatized airports are, on average, more efficient when compared to public airports. The target values from the analysis show the value to which the outputs can be increased to enhance efficiency.

This research work can be further extended to include more inputs such as operating costs and number of employees and more outputs such as operating revenue, cargo handled, etc. Since some

Figure 4. Relative efficiency score of the airports



of these airport services and infrastructure aspire to compete with world- class airports, then it will be interesting to compare these major Indian airports to airports of comparable size, and a similar environment to determine how far Indian airports have progressed.

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REFERENCES

Airport Authority of India. (n.d.). Retrieved February 2013, from http://www.aai.aero/allAirports/blr_ti.jsp

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078–1092. doi:10.1287/mnsc.30.9.1078

Bengalaru International Airport. (2010). T1 Expansion Updates. Retrieved February 2013, from http://www.bengaluruairport.com/ourBusiness/terminalNews.jspx?sID=102#102

Bengaluru International Airport. (2010). About BIA. Retrieved February 2013, from http://www.bengaluruairport.com/ourBusiness/aboutBia.jspx

Button, K. (2006, September). Air transportation infrastructure in developing countries: privatization and deregulation. In *Fundación Rafael del Pino Conference on Comparative Political Economy and Infrastructure Performance: the Case of Airports*, Madrid (pp. 18-19).

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. doi:10.1016/0377-2217(78)90138-8

Chhatrapati Shivaji International Airport Mumbai. (n.d.). Master Plan. Retrieved February 2013, from http://www.csia.in/knowyourairport/masterplan.aspx

Cochin International Airport Ltd. (2007). About CIAL A Brief History. Retrieved February 2013, from http://cial.aero/contents/viewcontent.aspx?linkIdLvl2=51&linkId=51

Cochin International Airport Ltd. (2007). Airport Information Runway Characteristics. Retrieved February 2013, from http://www.cial.aero/contents/viewcontent.aspx?linkIdLvl2=6&linkid=91

Coelli, T. (1996). *A guide to DEAP version 2.1: a data envelopment analysis (computer) program*. Australia: Centre for Efficiency and Productivity Analysis, University of New England.

Cooper, W. W., Seiford, L. M., & Zhu, J. (Eds.). (2011). *Handbook on data envelopment analysis* (Vol. 164). Springer Science & Business Media. doi:10.1007/978-1-4419-6151-8

Delhi Indira Gandhi International Airport. (2013, April 15). Our Company. Retrieved April 2013, from http://www.newdelhiairport.in/our-company.aspx

Delhi Indra Gandhi International Airport. (2013, April 29). Fact sheet. Retrieved February 2013, from http://www.newdelhiairport.in/fact-sheet.aspx

Du, K., & Sim, N. (2016). Mergers, acquisitions, and bank efficiency: Cross-country evidence from emerging markets. *Research in International Business and Finance*, *36*, 499–510. doi:10.1016/j.ribaf.2015.10.005

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, *120*(3), 253–290. doi:10.2307/2343100

Gillen, D., & Lall, A. (1997). Developing measures of airport productivity and performance: An application of data envelopment analysis. *Transportation Research Part E, Logistics and Transportation Review*, *33*(4), 261–273. doi:10.1016/S1366-5545(97)00028-8

Heri Bezić, A. Š. (2010). Evaluating Airport Efficiency using Data Envelopment Analysis. *Advances Business-Related Scientific Research Journal*, *1*(1), 13–21.

Hyderabad Rajiv Gandhi International Airport. (2013, April 10). Retrieved April 2013, from http://www.hyderabad.aero/our-company.aspx

Hyderabad Rajiv Gandhi International Airport. (2013, May 8). Retrieved February 2013, from http://www.hyderabad.aero/rgia-hyderabad-ranked-3rd-in-the-world-by-aci.aspx

India International Flights. (n.d.). Dr. Babasaheb Ambedkar International NAG. Retrieved February 2013, from http://www.indiainternalflights.com/dr-babasaheb-ambedkar-international-airport.php

Investment Strategy for India (2006).

Juan, E.J. (2005). Airport Infrastructure: The Emerging Role of the Private Sector, Co-financing and Financial Advisory Services. Washington, DC: World Bank.

Koçak, H. (2011). Efficiency examination of Turkish airport with DEA approach. *International Business Research*, *4*(2), 204–212. doi:10.5539/ibr.v4n2p204

Kumar, A., Kaviani, M. A., Hafezalkotob, A., & Zavadskas, E. K. (2017b). Evaluating innovation capabilities of real estate firms: A combined fuzzy Delphi and DEMATEL approach. *International Journal of Strategic Property Management*, *21*(4), 401–416. doi:10.3846/1648715X.2017.1409291

Kumar, A., Luthra, S., Khandelwal, D. K., Mehta, R., Chaudhary, N., & Bhatia, S. (2017). Measuring and improving customer retention at authorised automobile workshops after free services. *Journal of Retailing and Consumer Services*, *39*, 93–102.

Kumar, A., Luthra, S., Khandelwal, D. K., Mehta, R., Chaudhary, N., & Bhatia, S. (2017a). Measuring and improving customer retention at authorised automobile workshops after free services. *Journal of Retailing and Consumer Services*, *39*, 93–102. doi:10.1016/j.jretconser.2017.07.007

Manzoor, K. P. (2010). Airport Privatization in India: Importance and Challenges. *IUP Journal of Infrastructure*, *8*(4), 58–69.

Ohri, M. (2012). Discussion paper: Airport privatization in India. *Networks and Spatial Economics*, *12*(2), 279–297. doi:10.1007/s11067-009-9117-8

Oum, T. H., Zhang, A., & Zhang, Y. (2004). Alternative forms of economic regulation and their efficiency implications for airports. *Journal of Transport Economics and Policy*, *38*(2), 217–246.

Pandey, A., Morris, S., & Raghuram, G. (2010). *Structuring PPPs in Aviation Sector: Case of Delhi and Mumbai Airport Privatization* (W.P. No. 2010-11-03). Indian Institute of Management.

Parker, D. (1999). The performance of BAA before and after privatisation: A DEA study. *Journal of Transport Economics and Policy*, *33*(2), 133–145.

Pels, E., Nijkamp, P., & Rietveld, P. (2003). Inefficiencies and scale economies of European airport operations. *Transportation Research Part E, Logistics and Transportation Review*, *39*(5), 341–361. doi:10.1016/S1366-5545(03)00016-4

Pillai, M. (2008). Infrastructure development and economic growth: The public private partnership (PPP) perspective. *The Journal of Infrastructure*, *6*(1), 24–31.

Sarkis, J. (2000). An analysis of the operational efficiency of major airports in the United States. *Journal of Operations Management*, *18*(3), 335–351. doi:10.1016/S0272-6963(99)00032-7

Talluri, S. (2000). Data envelopment analysis: Models and extensions. *Decision Line*, *31*(3), 8–11.

The Secretariat for the Committee on Infrastructure, Planning Commission, Government of India. (2006). Financing Plan for airports.

Veethi. (n.d.). Hyderabad Airport and its features. Retrieved February 2013, from http://www.veethi.com/articles/hyderabad-airport-and-its-features-article-53.htm

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