PERFORMANCE EVALUATION OF MAJOR INDIAN AIRPORTS -A MEASURE OF EFFECTIVENESS AND EFFICIENCY

By

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the University or other Institute of higher learning, except where due acknowledgment has been made in the text

Lakshmanan Ravi

Date 12th March 2013

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **"Performance Evaluation of Major Indian Airports- A Measure of Effectiveness and Efficiency"** by Lakshmanan Ravi in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Management) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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EXECUTIVE SUMMARY

India has seen unprecedented Aviation growth in the last 5 years and anticipated to grow further. From 50 operational airports in 2000, the numbers have increased to 82 in 2010. Passenger handling capacity at the airports has increased to 235 million in 2010 compared to 66 million in 2000. The number of aircrafts in 2010 was 413 against 100 in 1990. Still aircraft penetration in India is 2.8 million per aircraft compared to 1.14 in China and 0.15 in Australia. Thus there is a huge potential for the traffic growth in India.

The increase in traffic growth on continual basis year on year thus required rapid expansion and huge investment in the airport infrastructure. Thus, the Government of India (GOI) identified that the best possible option is private sector participation in the airport sector. GOI has taken a number of initiatives to encourage private sector participation in development, modernization and up gradation of airport infrastructure.

The new policy framework has brought out some major initiatives, both in the Greenfield and Brownfield airport developments. The Greenfield airports that are developed in India through Public Private Participation (PPP) are Cochin, Bangalore and Hyderabad. The decision to induct the private sector for modernizing the existing airports (Brownfield projects) resulted in the development of Delhi and Mumbai airports through PPP.

After the private sector participation (PPP) in the airport industry, a competitive environment has been created to a limited extent and the Indian airports are being listed among the overseas airports in Airport Service Quality (ASQ) rating for the first time.

The objective of this thesis is to prepare a measurement methodology for analyzing the performance of airports and apply this to 7 major airports in India and evaluate the performance of these airports. The airports are Delhi, Mumbai, Chennai, Bangalore, Kolkata, Hyderabad and Cochin. Out of these airports Chennai and Kolkata are operated and maintained by Airports Authority of India (AAI) and the remaining airports are operated and maintained under Public Private Participation (PPP).

This research is worthwhile as the performance evaluation of Indian airports, that too a few are based on Airport Service Quality (ASQ) rating through passenger satisfaction survey conducted by Airports Council International (ACI). Even though among the airports they bench mark their performance sometimes, the assessment is based on partial productivity factors.Most importantly there is a requirement to carry out a comprehensive performance evaluation of major Indian Airports, as this has not been carried out yet.

The methodology adopted is to evaluate the performance on effectiveness and efficiency of the airports. Effectiveness of the airport is the ASQ rating obtained by the airport through passenger satisfaction survey which is a published data. The efficiency is evaluated by segregating the productivity and financial efficiency of the airports. Performance evaluation of the airports has been carried out in terms of its productive efficiency of their infrastructure, on annual traffic movement and peak hour traffic movement. The financial efficiency is arrived at using the partial financial measures but by evaluating overall performance.

Literature survey shows that Data Envelopment Analysis (DEA) has been used for the performance evaluation of airports and the method is best suited, as airports use multiple inputs and produces multiple outputs. DEA always identify **at least** one institution as being best practice within the given sample set. Thus, the **efficiency scores derived from DEA are best seen as relative efficiency scores-** the efficiency of an institution relative to what is identified as the best practice institution. Hence, productive efficiency is evaluated for the following three groups of airports

a) Group1- 40 Airports consisting of 17 Indian Airports and 23 overseas airports

b) Group-2- 27 Airports that handled more than 5 million passengers per annum, out of the 40 airports in Group 1 consisting of 6 Indian Airports and 21 overseas airports. (only 6 Indian airports have handled more than 5 million passengers per annum)

c) 17 Indian airports out of 40 airports in Group 1

The partial productivity factors on financial aspects are very useful for the performance evaluation. However, individual ratios does not provide a comprehensive performance evaluation and hence, **Surface Measure of Overall Performance (SMOP)** method is found appropriate using multiple partial performance indicators as performance measures.

The output and input variables for DEA methodology and partial financial measures for SMOP methodology have been chosen based on certain analogy.

The performance evaluation of the airports shows that there is no relation between ASQ and the efficiencies. High ASQ does not translate to high efficiency. The airports which have lesser productive efficiency mean they have the capacity to handle traffic growth without the need for additional infrastructure. There is no relation between the ownership of the airports (PPP or AAI) in respect of financial efficiency or productive efficiency. However, the ASQ rating of PPP airports are better than that of AAI airports. The productive efficiency of airports based on annual traffic and peak hour traffic is not the same.

The thesis consists of 6 Chapters. In the **First Chapter** the necessity of performance evaluation of airports, the presently known indicators of performance of Indian airports, challenges for airport industry, the Research Objective and Research Methodology have been presented. A review of the literature pertaining to efficiency analysis of airports and other industries using various methodologies has been presented in the **Second Chapter**. Proposed methodology for performance evaluation of airports with measurement perspectives and performance indicators have been presented in the **Third Chapter**. Productive efficiency of airports has been calculated using Data Envelopment Analysis (DEA) and presented in the **Fourth Chapter** and brief description of terms used in DEA, identification of relevant input & output parameters and sample size for the analysis are included in this Chapter. In **Chapter Five** the financial evaluation has been carried out using Surface Measure of Overall Performance (SMOP) with a brief about the methodology and the revenue and cost of an airport. In **Chapter Six** findings and conclusions are presented with the summary of the productive, financial efficiencies of the 7 airports chosen including input and output targets and their effectiveness score. The limitations of the Research and further study on this subject are also included in this Chapter. References and appendices are added at the end.

LIST OF ABBREVIATIONS

AAI - Airports Authority of India

ACI - Airports Council International

AERA - Airports Economic Regulatory Authority

ASQ - Airport Service Quality

ATM - Air Traffic Movements

BCC - Banker, Charnes & Cooper

BOO - Build Own Operate

BOOT - Build Own Operate Transfer

CAPA - Centre for Asia Pacific Aviation

CCR - Charnes, Cooper, Rhodes

CISF - Central Industrial Security Force

CRS - Constant Returns to Scale

DEA - Data Envelopment Analysis

DF - Development Fee

DMU - Decision Making Unit

DRS - Decreasing Returns to Scale

EBITDA- Earnings Before Interest, Taxes, Depreciation and Amortization

GOI - Government of India

IATA - International Air Travel Association

ICAO - International Civil Aviation Organization

IRS - Increasing Returns to Scale

JVC - Joint Venture Company

MOCA - Ministry of Civil Aviation

MPPA - Million Passengers Per Annum

MPSS - Most Productive Scale Size

OMDA- Operation, Management and Development Agreement

PAX - Passengers

PPH - Peak Passengers Per Hour

PPM - Partial Productivity Measures

PPP - Public Private Partnership

PTE - Pure Technical Efficiency

RNFC - Route Navigation Facility Charges

SE - Scale Efficiency

SMOP - Surface Measure of Overall Performance

TFP - Total Factor Productivity

WLU - Work Load Unit

VRS - Variable Returns To Scale

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

1.1.1 PERFORMANCE OF AIRPORTS

Evaluation of performance of airports has attracted lot of attention world over due to change of ownership from public to private or PPP model. India is not an exception for this interest as some major airports have moved from Airports Authority of India (AAI) to Joint Venture Companies (JVC) under Public Private Partnership (PPP) and more airports are being planned through PPP. There is a huge expectation from the JVC in terms of development of the airport & its facilities and also for increased productivity at the airport. These days the airports are under constant watch by the airlines and other stake holders to assess the airports productivity. One of the important aspects of the airport operation is to see how well the assets are utilized. Hence, it is essential and appropriate to evaluate the productivity at an airport, to ascertain how well the resources and infrastructure have been utilized for the output achieved.

1.1.2 GROWTH OF AVIATION IN INDIA

Airlines

The government-owned airlines dominated Indian aviation industry till the mid-1990s adding fleet progressively. To encourage the Civil Aviation growth in India, the Government adopted Open sky policy in 1990 which allowed air taxi-operators including the private operators to operate flights from any airport, both on a charter and a non-charter basis and to decide their own flight schedules, cargo and passenger fares. As part of its open sky policy in 1994, the Indian Government ended the monopoly of IA and AI in the air transport services. By 1995, several private airlines had ventured into the aviation business and accounted for more than 10 percent of the domestic air traffic. Today, Indian aviation industry is dominated by private airlines and these include low cost carriers, who have made air travel affordable. The advent of these private airlines therefore played a key role in the increase in air traffic calling for further developments and improved facilities at airports.

The scenario of the Indian Civil Aviation is aimed at a gigantic make over through the next decade by targeting to achieve an equivalent of what it has scored in the last century. India's vast unutilized air transport network has attracted several investments in the Indian air transport industry in the past few years. The fact that the Indian Airports are not prepared to handle the huge increase in the number of passengers has to be accepted and hence up gradation of the airports and construction of new airports is necessitated.

To keep up with the growing Air Passenger Traffic the fleet size has also grown during the period 2004-05 to 2010-11 from 184 aircrafts to 539 aircrafts. As of August 2011 the fleet size has crossed 500. Private airlines are planning to add another 500 aircrafts in the near future. According to projections made by Boeing, over the next 20 years (2029-30), the Indian market would require 1,000 commercial jets valued at approximately $100 billion.

Airports

Indian airports were managed by Civil Aviation Department, Government of India, till the creation of International Airports Authority of India (IAAI) in 1972 and National Airports Authority (NAA) in 1986. In 1995 Airports Authority of India (AAI) was established by merging both IAAI and NAA by an Act of Parliament –The Airports Authority of India Act in 1994 –for better and efficient management of all airports in India by a single Authority.

Civil Aviation sector is fast emerging as a mode of mass transport as against a sector providing transport services to the elite sections of the society visualized earlier. It is now effectively competing with rail and road transport. It has distinct advantage of saving time over longer distances and accessing difficult terrain by road. In order to meet this increasing demand in air traffic and encourage more passengers to travel by air it requires reduced congestion at the airport terminal, unhindered and efficient services, improved landing slots, adequate parking bays and easier traffic movement during peak hours for airlines, besides ensuring stringent security & quality standards.

The New Civil Aviation policy (1997) allowed private investment in the air infrastructure sector, including foreign equity investments. Automatic approval would be given for foreign equity investments up to 74 % and 100 % in special cases, for construction of green field airports or up gradation of existing airports. State Governments, urban local bodies, private companies, individuals and joint ventures are allowed to invest. Investment is allowed in the form of Build-Own-Operate (BOO) and other forms depending on 20 circumstances.

The policy also stipulates that, air traffic control & communication Navigational services will continue to be provided by AAI and Security, Customs and Immigration services by the Government.

The passenger traffic has grown tremendously during the last five years. It has grown from 59.2 million in 2004-05 to 162.3 million in 2011-12 showing an overall growth of 174% (Source: AAI Traffic News). The main factors contributing to this growth include the growth of the economy, falling fares, and increasing capacities of domestic private airlines. The passenger traffic of 143 million in year 2010-11 is anticipated to increase to 452 million by 2020-21 [Source- CAPA]

The following figure show the statistics to indicate the growth of the passenger traffic and air traffic movements (ATM)

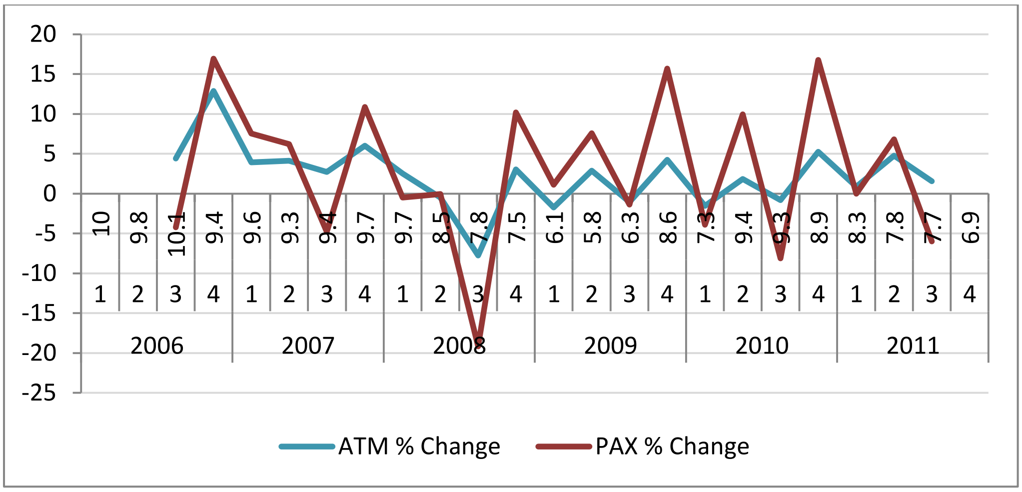

Fig 1.1 Trend of ATM and Passengers (Source: AAI)

The above comparison shows the Air Traffic Movement growth with respect to the passenger growth. The graph depicts that the percentage change in the ATM year to year remained more or less the same whereas the change in passenger growth is very high which means the load factor of the aircraft is increasing. This puts more pressure on the airport facilities and services.

In the context of globalization, airports are the gateways to a country and will act as catalysts for growth. But building airports requires huge capital investment, and the same from the government front has become a herculean task. Hence, Government of India decided to introduce Public Private Participation (PPP) for the development of the airports. PPP model allows efficient development of infrastructure by combining the strengths of the public organization, with the entrepreneurial skills and business acumen of private enterprise. Tourism is one of the factors for growth in the International passengers. However the trend shows a decline in the percentage of tourism passengers compared to the total international passenger traffic. This implies that people world over prefer coming to India for business purpose, which means the infrastructure at airports is to meet the expectations of business travelers. Figure below shows the foreign tourist numbers in comparison with International Arrival Passengers i.e., business purpose and tourism purpose.

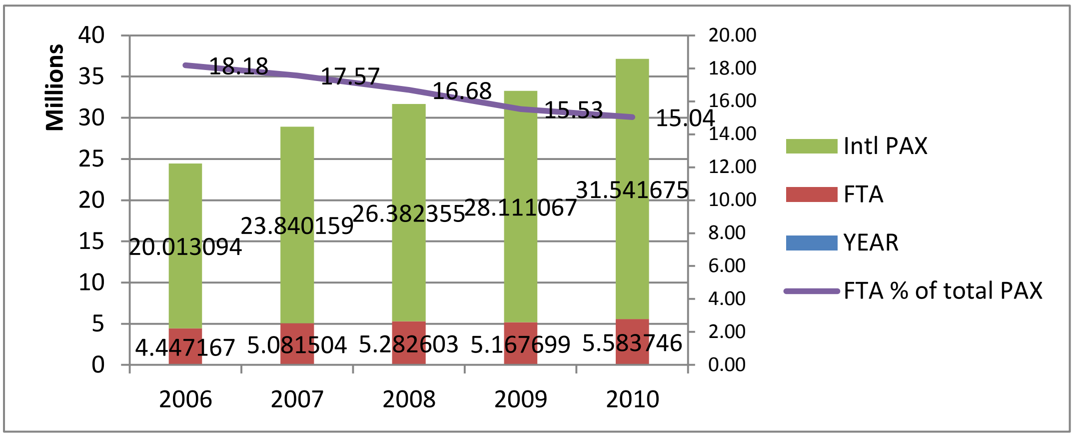

Fig 1.2 International tourist versus total arrival passengers (Source: Ministry of Tourism and AAI)

It is also foreseen that, in order to tap the vast potential of growth of traffic and to encourage a balanced growth of civil aviation, Regional Airlines will prompt

Government to develop the Regional Airports through more liberal policies for provision of better infrastructure facilities.

State of the art IT systems and airport systems adopted by the infrastructure providers has led to quick turnaround times for the airlines and better processing of the passenger and Cargo which lead to improved business and customer satisfaction. In-line baggage screening, automatic baggage reconciliation, automated services etc. has changed the scenario and benchmarking of Indian airports. All airports now look into inducting the best technology available with improved management practices.

1.1.3 AIRPORT MANAGEMENT, AIRPORT OPERATIONS AND ITS COMPLEXITY

Before the private sector participation in Indian airport sector, attention to individual airports on business front was not focused as AAI was making profit overall with all airports together and with major source of revenue from RNFC. After the private sector participation, airports are seen as individual profit centers and more focus on business for their survival and viability is seen. Today each airport is seen as a business entity. Hence, performance evaluation of financial efficiency becomes relevant and essential.

Coupled with the many achievements are the challenges the airport business face today. Most important challenge is to improve airport revenue, reduce cost and comply with the terms and conditions of the concession agreements signed by the PPP airports in terms of the development of the airport and meeting the objective and subjective quality parameters.

Airport operator while operating, maintaining, managing the airport and providing services, carries out various activities. These activities are the enablers for processing the passengers and their baggage, handling of freight; provide facilities at the airport for the convenience of the passengers, aircraft operators and other stakeholders and for safe aircraft operations.

Activities at airport [21] can be broadly classified into the following groups

Airport Operation

- Air-traffic Management (ATM)
- Communication & Navigational Services (CNS)
- Meteorological services
- Terminal Operations including facilities management
- Facilities management of other buildings
- Airside operations – Airfield maintenance – (Runway, taxiway, apron) Aircraft Fire & Rescue Services
- Utilities Management- Power, water & sewerage
- Aviation Safety- Environment Management, Obstacle monitoring, Bird control,
- Waste management

Aircraft Handling

- Provision of Ground Power, pre-conditioned air, water
- Refueling of aircrafts
- Cleaning of aircrafts
- Waste collection and disposal
- Docking of passenger boarding bridges or ladder
- Loading and unloading of passenger bags & belly cargo

City side management- Car parking, access to airport, traffic management, security other than aviation security

Sovereign functions

- Customs
- Immigration
- Aviation security

Commercial activities within the terminal building

- Duty free shops
- Retail shops- Books & Magazines, Food & Beverages, medical, electronics, toys etc.
- Banks, Car rental, hotel & restaurants, visitors lounge
- Airline lounges, Nap & shower facilities and Hotel

Commercial activities outside the terminal building but within the airport

- Hotels, offices, commercial establishments, golf courses, office complex, conference complex, exhibition Centers, hospital
- MRO
- Cargo complex
- Aircraft hangars

Activities off Airport

Consultancy services to other airports, JV with other airport companies, commercial activities outside the airport like aviation training academy etc. Not all the activities at an airport are carried out by the airport operator. In the Indian context air traffic management, communication & navigational services are to be provided only by AAI for civil airports and Ministry of Defence in the case of Defence airfields. Similarly the Metrological services are provided by Indian Metrological Department. Customs and Immigration services are carried out by Government of India and Aviation Security by CISF. Aircraft handling activities and check-in process are carried out by Ground Handlers which could be airlines themselves or by a third party including airport operator. The commercial activities at the airport are carried out either by the airport operator themselves or by a third party or a JVC between a third party and the airport operator.

The activities being carried out by the airport operator entail cost and majority of them are revenue generating activities.

1.1.4 CHALLENGES FOR AIRPORT INDUSTRY

Despite all the good happening in the Aviation Industry, airlines are struggling to reduce the cost in view of unpredictable fuel price and competitive environment. At the same time, the airports which have been investing huge capital to improve the infrastructure at the brown field airports or by developing green field airports, have the tough task in hand to invest in capital and also to increase revenue and reduce operating cost and thereby make a reasonable return on their capital invested. Thus, performance evaluation of the airports on productive efficiency and financial efficiency becomes important.

Some of the challenges the airports face are

High capital cost

The airport facilities, capacities cannot be incrementally increased based on traffic growth on a year- to- year basis. Hence, the airport operator creates capacities for projected traffic growth for a span of at least five years. Till the traffic reaches the projected growth, there will be some infrastructure which may not be fully utilized and hence, during this period the revenues may not match with the cost. This may necessitate user development fee or increase in aeronautical tariff. Hence, optimum development of infrastructure is important.

Airport Charges

There is a general perception that privatization of airports lead to higher charges. Hence, any tariff revision or levy of DF creates unhappiness among the travelers, airlines and airline associations (IATA).

The tariff for aeronautical services was revised up by 10% in 2009 after 8years. When the airport operators submitted the revised tariff in the year 2011 concerns from the airport community was widely seen. Even though the airport charges are 3 to 4 % of airline operating cost, in view of financial positions of the airlines with high and volatile fuel cost any increase of the airport charges is seen as a threat to the passenger growth. Even though the AERA has a consultation process with the users, there is a total negative publicity against the proposal to increase the airport charges.

Running Cost

Airport’s running cost is inflexible - the running cost does not change proportional to the traffic changes. More competition among airports is a good sign for the airlines. However, the airport operator should realize this and bring in operational efficiency with reduced cost

Peak Hour Traffic

Airports are designed for peak traffic hour, whether it is number of aircrafts or number of passengers. However during non-peak period of the day the facilities are underutilized. The airport operator's challenge is to increase the number of peak hours in a day when the traffic rises in order to minimize the additional infrastructure requirement .However, airlines consent to operate during the time period proposed by the airport operator can only be obtained when there is a demand. Hence this may not be always practicable.

Seasonal Variations

The airport operator has to bear in mind the lean season of a year besides economic slowdown which will impact the airport revenue.

Passenger Expectations

The expectations of the passengers while at the airport have changed dramatically in the recent past, which poses challenge to the airport operators. Keeping up with the service quality and competing in the race of passenger satisfaction has significant impact on the airport operation and management. Investment to keep up with the technological advancement is a must for the airport operator.

ATM/CNS Infrastructure

In parallel to development of airports to meet traffic growth, ATM/CNS infrastructure must also be upgraded to improve the safety and to cater for the traffic, while maintaining cost efficiency and environmental awareness. These services are provided by AAI and a close coordination is required to achieve the ATM/ CNS efficiency.

Non-Aeronautical Revenue

Practicability of increasing the non-aeronautical revenue by innovative methods is limited, particularly for the airports whose passengers are price sensitive.

Stakeholder Management

For the passengers the responsible one at the airport is the airport operator. However, the airport operator does not perform all the functions of airport operation. In the last few years one perceptible change is that airport operator manages all the stakeholders of airport operation, from the airlines to government service providers like Customs, immigration & security, to get the best out of them, even though he does not perform these functions directly.

Airport operator is under constant watch by the regulatory agencies, passengers, stake holders and community around the airport.

In view of the fact that airports have moved from being seen as terminals and processing facilities to business, it is essential that a comprehensive evaluation of their performance is carried out and benchmarked with other airports to improve their performance and in turn their efficiency.

1.2 OBJECTIVES OF THE RESEARCH

The first objective of this thesis is to prepare a measurement methodology for analyzing the performance of airports and apply this to major airports in India and evaluate the performance of these airports.

The second objective is to compare the performance on productive efficiency on annual basis (passenger & cargo movement through the airport) and the peak hour traffic movement and overall financial efficiency.

The third objective is to compare the productive efficiency, financial performance and the ASQ rating of the 7 airports whose performance is being evaluated and identify any correlation between these.

1.3 RESEARCH METHODOLOGY

1.3.1 STATEMENT OF THE PROBLEM

Currently the Indian Airports performance, that too of few airports, is evaluated based on

Service Level Achieved as per the concession agreement or Operation, Management and Development Agreement (OMDA) between the JVC and the AAI. There are certain *objective* quality parameters specified in these agreements. Example- maximum queuing time at Check-in, time for baggage delivery, on-time performance of the flights, etc. The parameters measured are in **Appendix 1.** The airport operator measures these parameters and submits the report to AAI.

***Subjective* quality parameters** evaluated through the Airport Service Quality (ASQ) program to evaluate the level of service / facilities provided at the airports. This is a passenger satisfaction survey. ASQ survey is being conducted by Airports Council International (ACI) four times in a year. The survey consists of minimum of 1,400 passengers per year randomly selected to take part in the survey at each airport, guaranteeing statistically accurate results. The ASQ scores between the airports are compared. The parameters measured in the ASQ survey is in **Appendix 2.**

The questionnaire containing the service parameters in Appendix 2 are distributed to select passengers and asked to rate in the scale of 1-5 (poor-1, Fair-2, Good-3, Very good-4, Excellent-5). In addition to the above, the passengers will be asked to rate the overall satisfaction with the airport.

As per the ASQ survey for the year 2010 (Source ACI), Delhi airport scored 4.49 and ranked 4th in the category of 25- 40 million passengers airports and 12th in the world ranking, whereas Mumbai is ranked 2nd in the 15-25 million passengers category and 21st in the world ranking and Hyderabad number 1 in the 5-15 million per annum category and 9th in the world ranking. The ASQ rating as a performance indicator is related only to the passenger satisfaction and the rating of the passengers pertain to the facilities provided at the airport. Also these are the reflections and perceptions of the passengers at the time of the survey and are subjective quality parameters.

1.3.2 NEED FOR THE PERFORMANCE EVALUATION OF INDIAN AIRPORTS

Assessment of objective or subjective quality parameters does not reflect the productive efficiency of the airport. Also the financial efficiency of the Indian airports is not assessed so far. **Hence, there is a need to evaluate the performance of Indian airports on productive efficiency and financial efficiency.**

1.3.3 SCOPE OF THE STUDY

The research focuses on 7 major airports in India. Performances of Indian airports evaluated are Delhi, Mumbai, Chennai, Bangalore, Kolkata, Hyderabad and Cochin. Out of these airports Chennai and Kolkata are operated and maintained by Airports Authority of India (AAI) and the remaining airports are operated and maintained under Public Private Participation (PPP). The year of performance evaluation is 2010-11.

1.3.4 RESEARCH DESIGN

1.3.4.1 DATA COLLECTION

The data are collected from the annual reports, airports' web site, ACI report, IATA report and contacts with the airports. The data analyzed is based on year 2010-11. For peak hour basis for the airports where published data is not available the peak number of passengers and ATM is arrived at by deriving numbers from the annual passenger numbers, flight schedules and the airport infrastructure.

1.3.4.2 TOOLS FOR ANALYSIS

Literature survey shows that Data Envelopment Analysis (DEA) has been used for the performance evaluation of airports and the method is best suited as airports use multiple inputs and produces multiple outputs. Hence, DEA method will be used for the productive efficiency.

For the financial efficiency evaluation, partial productivity factors on financial aspects are very useful for benchmarking. However, individual ratios do not provide a comprehensive performance evaluation and hence, **Surface Measure of Overall Performance (SMOP)** method is found appropriate using multiple partial performance indicators on financial aspects.

1.4 CONTRIBUTION OF THIS RESEARCH

The performance evaluation of seven major Indian airports has been carried out for the year 2011-11 in terms of their productive efficiency of the infrastructure and financial efficiency. The productive efficiency has been evaluated based on two basis, annual traffic movement as well as peak hour traffic movement. The output and input parameters for the calculation of productive efficiency and partial financial factors for calculation of financial efficiency have been chosen based on certain analogy. Analysis for the productive efficiency has been carried out in three groups, 40 airports, 27 airports that have handled more than 5 million passengers per annum and 17 Indian airports. The peers for the airports which have productive efficiency score less than 100 % have been identified with input and output targets. Sensitivity of the efficiency scores has been checked with analysis for the year 2011-12.

1.5 OUTLINE OF THESIS CHAPTERS

The thesis consists of 6 Chapters. In the **First Chapter** the necessity of performance evaluation of airports, the presently known indicators of performance of Indian airports, challenges for airport industry, the Research Objective and Research Methodology have been presented. A review of the literature pertaining to efficiency analysis of airports and other industries using various methodologies has been presented in the **Second Chapter**. Proposed methodology for performance evaluation of airports with measurement perspectives and performance indicators have been presented in the **Third Chapter**. Productive efficiency of airports has been calculated using Data Envelopment Analysis (DEA) and presented in the **Fourth Chapter** and brief description of terms used in DEA, identification of relevant input & output parameters and sample size for the analysis are included in this Chapter. In **Chapter Five** the financial efficiency has been calculated using Surface Measure of Overall Performance (SMOP) with a brief about the methodology and the revenue and cost for an airport. In the **Sixth Chapter** findings and conclusions are presented with the summary of the productive, financial efficiencies of the 7 airports chosen including input and output targets and their effectiveness score. The limitations of the Research and further study on this subject are also included in this Chapter. References and appendices are added at the end.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

This Chapter will present a review of literatures on productive efficiency analysis using various methodologies starting with partial factor productivity, balanced score card method, Stochastic Frontier Analysis. More focus will be on Data Envelopment Analysis (DEA) and Surface Measure of Overall Performance (SMOP) methodologies as the airports use multiple inputs to produce multiple outputs. Literature reviews of efficiency analysis of industries other than airports are also carried out. The review includes documents published by International Organizations like ICAO and IATA.

2.2 LITERATURE ON EFFICIENCY ANALYSIS

Partial Factor Productivity & Total factor Productivity

To ascertain the economic performance of European airports **[1]** used partial productivity indicators with a focus on financial variables.

[2] Identified if private airports perform better than public ones and used PFP indicators and regressions on financial and operational performance. Since PFP considers only one aspect of performance.

Total factor Productivity (TFP) for five Australian airports using financial parameters of the airport has been calculated in **[3]**. The inputs used are operating cost, capital cost and other costs and the outputs used are aeronautical revenue and non-aeronautical revenue. Firstly the gross TFP is used, where revenues weight the index. Then, the results from gross TFP are compared to output-adjusted TFP, where a simple regression is used with output as independent variable and TFP scores as dependent variables. In conclusion, further research with at least 10 years of data and association of TFP scores to influencing factors are suggested for a more reasonable application of this methodology.

Comparison between ranking using TFP and PFP methods have been made for 25 European airports in **[4]** and concludes that rankings provided by PFP indicators are significantly different than that of methodology using TFP.

Balanced Score Card Method (BSC)

Using Balanced score card model **[5]** it is evaluated whether airport privatization is a success or failure.

Stochastic Frontier Analysis (SFA)

The efficiency of UK airports has been measured **[6]** using Stochastic Latent Class Frontier model and the aim of the research was to measure the heterogeneous efficiency. The overall conclusion is that heterogeneity is a major issue in airports and they should be analyzed in relatively homogeneous clusters. Economies of scale related to dimension that blur heterogeneity in airports.

Data Envelope Analysis (DEA)

[7] Analyzes 12 Australian airports for the period 1990-2000. Explains why PPF is not appropriate and TFP measure is the right way. Using total revenue of the airports as an indicator of output is justified when the prices, and therefore revenue, are not reflection of the degree of market power of the institution. Malmquist DEA approach uses panel data to estimate changes in technical efficiency, technological progress and total factor productivity. This approach derives an efficiency measure for one year relative to the prior year, while allowing the best practice frontier to shift. Two outputs are number of passengers and amount of freight. The three inputs are number of staff employed, the capital stock in constant dollars using perpetual inventory method and the runway length. DEAP software (Coelli 1996) is used. DEA model is of input orientation since it is assumed that airports have fewer controls over outputs than they do have over inputs and assumes VRS. In the next stage, the performance of these 12 Australian airports is evaluated by including three New Zealand airports, two British airports, two Canadian airports and five American airports. Two outputs are number of passengers and amount of cargo. Inputs are staff, combined lengths of runways, the land area of airports, and the number of aircraft standing areas. Combined length of airstrips and number of stand areas are used as proxies for capital. Concludes that Airports have high- income countries that have a high level of service quality and all operate international services with internationally accepted standards. Results may not be entirely under the control of managers of various airports. The airports in the different countries operate in different economies and different regulatory climates, therefore changes in efficiency may be reflection of these factors than the management of airports.

Efficiency of major NE Asia airports has been analyzed in **[8]** for the period 1994 to 2007. The analysis was for 7 airports, using both CCR and BCC models, CRS and VRS and Windows Analysis. The aim of the study was to identify the efficiency trend over the years of the study. The inputs considered are runway length, terminal size and employees and the outputs were passenger volume, cargo volume and aircraft movement. The paper concludes that more airports should be considered for analysis and number of inputs and outputs should be increased and any analysis should investigate the intrinsic differences among airports from different countries.

Research on the performance measurement of 16 German Airports by **[9]** considered number of check-in counters, number of gates, the airport size, number of runways and number of car parking spots. Only passenger volume was considered as single output, as this study was also part of an analysis with Stochastic Frontier Analysis (SFA). Airports with 50 million to 0.5 million per year is used. The efficiency analyzed was for the year 1998-2005. The analysis uses VRS methodology and output oriented. Work Load Unit (WLU) selected on previous study did not lead to sufficient results. The question is if the effort for handling passenger is comparable to the effort of handling a 100 kg cargo. It mentions also why cost and annual capacity as a cost allocation cannot be used in view of varying quality and specifications of materials and finishes among the airports. The paper compares DEA and SFA methodologies for evaluating efficiency and concludes that there is no a priori reason which is better. The paper also mentions that more work has to be done in the adjustment of inputs and outputs in the future.

The productivity measures are developed for terminals and airside operations in **[10]**. The analysis includes identification of the variables that the managers have some control over and what the relative importance of each variable in affecting the performance. The data set contains 21 US airports over a five year period (1989-93). The paper brings out that the necessity to separate cost efficiency, service effectiveness and cost effectiveness and to develop performance measures. Terminal services are modeled as having two outputs- number of passengers and cargo volume and six inputs -number of runways, number of gates, terminal area, number of employees, number of baggage collection belts and number of public parking spots. Airside operation model has two outputs- air traffic movements and Passenger movements and four inputs- airport area, number of runways, runway area and number of employees. CRS methodology is used for airside operations and VRS for terminal services. The model used is output orientation. The research mentions that this is only a start and the next step is to integrate cargo information into the output and better to integrate the airside and terminal operations.

Various models of DFA have been analyzed in **[11]** for 45 airports for the period 1996-2000. In this paper inputs are operating expenses, non-operating expenses, number of runways & number of gates. Outputs used are aero revenue, non-aero revenue, on-time operations, number of air carrier operations & number of other operations. Output orientation measure is used in the analysis. It suggests that it is worth to carryout additional analysis relating to selection of outputs and inputs. Any study needs to present a discussion of what the true goals of airport namely maximum throughput passenger or aircraft or profit, minimizing delays etc.

[12] In the Thesis titled "Establishing the Practical Frontier in Data Envelopment Analysis" explains the various models of DEA methodology, the importance of choosing appropriate inputs and outputs. Also from the DEA efficiency scores the units are classified as robustly efficient units (1 and appears as reference units for many DMUs), marginally efficient units (1, but appear one or two reference sets), marginally in-efficient units (> 0.9, less than 1), distinctively in-efficient units (less than 0.9). Also explains sensitivity analysis checks by either of the three methods viz. adding or deleting DMUs, adding or deleting inputs or outputs and decreasing or increasing the number of inputs or outputs.

[13] Analyzes U.S. Airports to determine if there is a relationship between size and efficiency of an airport. Inputs used are the operating expenses, the non-operating expenses, the number of runways and the number of gates and the outputs are the number of passengers, the number of air carrier operations, the number of other operations, the aeronautical revenue, the non-aeronautical revenue and the percentage of on-time operations as outputs.

Analysis for 34 European airports using DEA methodology has been conducted **[14]** considering terminal operations and airside operations as a separate entity. The period of the performance evaluation is 1995-1997. The inputs and outputs considered in the analysis are as below

Inputs	Outputs
Terminal Operation:- Terminal area, no. of aircraft bays, number of check-in desks and baggage claim belt numbers.	Passenger numbers and ATM
Airside:- Total airport area, total length of runway, number of aircraft bays	Passenger numbers and ATM

Financial performance of 35 European airports for the year 1990-2000 has been assessed in **[15].** It compares airports among public- private, fully private and public. Partial productivity factor, financial ratios and DEA are evaluated to investigate differences attributable to degree of changes in performance after a change in ownership. Total revenue as output would assess the financial efficiency, number of passengers or cargo throughput would assess physical efficiency. Total cost is considered as input. VRS and input orientation is used. The analysis show medium sized and small airports show IRS and airports with volume in excess of 4 million passengers show either CRS or DRS. Trend shows decreasing scale efficiency in parallel to increasing traffic volume. High efficiency of DEA for partially & fully privatized airports.

Capacity Measurements in the Airport Sector has been presented in **[16]** using Declared Capacity instead of Conventional Benchmarking Methods. The paper challenges the conventional method of calculating the capacity with DEA or SFA using inputs such as number of runways, length of runways. It also mentions that in view of nature of services terminal and airside should be separately assessed. Also explains the problems in the use of number of employees as input.

[17] Measures the airport quality from the airlines view point using DEA. The objective of this paper is to develop a model to determine the relative efficiency and quality of airports from airlines' point of view instead of passengers'. Airport quality parameters using subjective airport quality parameters have been replaced with quality from airlines view point. Airlines evaluated a number of European and non-European airports by means of a detailed questionnaire. Statistical analysis of the median score has shown that these evaluations vary considerably relative to quality factors and airports. The key methodology in this study to determine the relative quality level of the airport is DEA which has been developed through the use of principle component analysis (PCA). The outputs represent levels of satisfaction from the use of each airport and the inputs are airport charges, minimum connecting time, number of passenger terminals, number of runways and the distance to nearest Centre. VRS method with input orientation was used.

Air Transport Research Society (ATRS) [18] publishes bench marking report every year. In the study for the year 2011, 156 airports were considered. The analysis used Variable Factor Productivity (VFP) Index, DEA and SFA. The bench marking is carried out for overall operating efficiency, cost competitiveness and Airport User Charges. VFP is essentially the ratio of total (aggregate) output index divided by total (aggregate) variable input index, namely labor and soft cost input (total non-labor variable inputs). Residual (Net) variable factor productivity (RVFP) measures after removing effects of the Factors which are beyond managerial control.

Bench marking analysis of Spanish Commercial Airports has been carried out **[19]** comparing SMOP method and DEA ranking method. This paper evaluates the efficiency of the airports using SMOP method, comparing on two aspects, based on best observation and average. On DEA methodology it uses cross-efficiency matrix and super efficiency model and analysis of virtual airport and comparison of the rest of the airports. The paper concludes that the cross-efficiency method as the best alternative to rank the airports performance.

Technical efficiency of Airports in Latin America has been studied in **[20]**

2.3 OTHER LITERATURES

International Civil Aviation Organization (ICAO) [21] has published "Airports Economic Manual". In this manual the financial performance indicators have been classified as

- Strategic Indicators (example- Return on capital investment)
- Tactical Indicators (example- Revenue per pax)
- Day to day Indicators (example- Cash flow)
- Target Indicators (example- Cost improvements)

Transportation Research Board (TRB) [22] sponsored by Federal Aviation Administration through Airport Cooperative Research Program classifies the Airport Performance Indicators (API) as Core, Key and others, depending on whom the information is relevant. The CEO or Airport Director or the Board will be interested in the Core APIs, which are 29 nos. Key APIs are meant for departmental heads and other APIs for secondary departmental heads. Some of the APIs will be for self-benchmarking (change over time) and some of them for peer benchmarking.

Airports Council International (ACI) [23] has published a Guide to Airport Performance Measures. The guide identifies six performance areas viz. Core, Safety & Security, Service quality, Productivity, Financial & commercial and Environmental.

2.3 LITERATURES ON DEA METHODOLOGY USED FOR INDUSTRIES OTHER THAN AIRPORTS

[24] Has evaluated the technical efficiency of 44 State Transport Undertakings for one year 2000-2001, using DEA method. The analysis uses both CCR and

BCC model and evaluates the scale efficiency, technical efficiency and pure technical efficiency. Fleet size and cost / bus/ day are the inputs and kilometer/bus/day and Revenue/bus/day are the output. This paper mentions that DEA scores are sensitive to input and output specifications and the size of the sample. It mentions that the number of DMUs should be greater than two times the total number of variables.

[25] A research paper on measuring bank branch performance using DEA: the case of Turkish bank branches. The research has been carried out for 128 bank branches. The analysis is with 3 inputs and 8 outputs for production approach and 3 inputs and 2 outputs for profitability approach. The DEA using CCR and BCC models are used to evaluate both technical efficiency and pure technical efficiency and from these the scale efficiency.

2.5 LITERATURES ON SMOP METHODOLOGY USED FOR INDUSTRIES OTHER THAN AIRPORTS

Paper about bench marking national labour market performance **[26]** brings out the necessity & methodology for standardization of the data, influence of the axes in the radar chart on surface area of polygon and correlation between indicators.

Working Paper on Benchmarking labor market performance and labor market policies: theoretical foundations and applications **[27]** provide further insight to the SMOP methodology.

Radar charts has been used for presenting multivariate health care data **[28]**

2.6 CONCLUDING REMARKS

LIMITATIONS OF EXISTING LITERATURES

The existing literatures have not focused on a comprehensive performance evaluation of Indian airports, in terms of their productive efficiency of the infrastructures and overall financial efficiency. There is no comparison of the service quality delivery with productive efficiency and overall financial efficiency. The productive efficiency analysis carried out so far have focused on the annual passengers and cargo throughput at an airport whereas there is no evaluation carried out for the productive efficiency during peak hour traffic movement through an airport passenger terminal building. In most of the previous studies the selection of input and output parameters were based on data availability. The rationale for choosing the output and input parameters for the efficiency analysis has not been described. Based on the literature survey following further study are identified and carried out in this research**.**

a. *Performance evaluation perspectives of airports*
b. *The basis for the selection of input and output parameters for the DEA methodology*
c. *The performance evaluation of airports based on two aspects, on annual basis including cargo & passenger and only with reference to passenger terminal building for the peak hour traffic.*
d. *Use of partial productivity factors on financial aspects to evaluate a comprehensive financial performance of the airport, using SMOP methodology*
e. *Comparison of performance on Effectiveness, and Efficiency (Productivity and Financial)*

CHAPTER 3

PERFORAMNCE MEASUREMENT METHODOLOGY

3.1 OVERVIEW

This Chapter will present three perspectives on which the performance of an airport can be measured, the necessity to measure both the efficiency and effectiveness and will evolve a performance methodology for airports

3.2 PERFORAMNCE MEASUREMENT PERSPECTIVES

The airport performance measurement perspective can be broadly classified in to three categories- Operational Perspective, Financial perspective and Community perspective **[5]**

3.2.1 OPEARATIONAL PERSPECTIVE

Under this are the subjective and objective service quality measurements. The ASQ rating is the subjective service quality measurement. The objective service quality parameters as per OMDA/ Concession agreement are the service delivery to the passengers. Productive efficiency assessment of infrastructure is also part of this perspective to know how well these have been utilized and if there is a necessity to expand or add infrastructure.

3.2.2 FINANCIAL PERSPECTIVE

This is to examine the financial aspects of an airport in terms of its revenue, operating cost, and EBITDA among others. These individual parameters do provide performance measure of an airport for its own evaluation over a period of time but difficult to compare with other airports due to different business model and activities carried out at airports. Even though financial performance is important, does not show its productivity. An airport's objective is not simply to maximize profits but also to provide efficient and quality services.

3.2.3 COMMUNITY PERSPECTIVE

The assessment under this measurement is based on the fulfillment of social responsibility by the airport in terms of noise abatement, pollution control, water conservation, employment opportunities for the local community, health care, etc. Many of the airports do spend considerable efforts in these areas.

This research focuses on operational and financial perspectives.

3.3 EFFECTIVENESS & EFFICIENCY

Effectiveness is the extent to which outputs of service providers meet the objectives set for them. Whereas the Efficiency is the success with which an organization uses its resources to produce outputs — that is the degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical or productivity, allocative, cost and dynamic efficiency. An organization might increase its measured efficiency at the expense of the effectiveness of its service. Hence, improving the performance of an organizational unit relies on both efficiency and effectiveness.

There is a need to separate cost efficiency, service effectiveness and cost effectiveness and to develop performance measures **[10].**

3.4 EVOLVING PERFORMANCE METHODOLOGY

In order to evaluate airport performance it is essential to assess both the effectiveness and efficiency. Effectiveness is measured through the Airport Quality Service (ASQ) ratings and the evaluation of the objective service quality parameters performed by the airport.

Efficiency is measured on two aspects viz. through the evaluation of productivity of an airport, assessment of productivity of the infrastructure created, in terms of its inputs & outputs and through evaluation on financial aspects. Assessing the airport performance is complex as there are many variables and comparing with other airports is to be done with caution as no two airports are similar.

3.4.1 PERFORMANCE INDICATORS

Transportation Research Board (TRB) [22] has classified airport performance indicators into three categories, as

- Core performance indicators
- Key performance indicators and
- Others

Core performance indicators are the ones that are important for airport overall operations- Annual Aircraft Operations, Concession revenue as percentage of total operating revenue, Non- aeronautical revenue as percentage of total revenue are the few examples

Key indicators are important for the departmental level – Utilities cost of terminal per square feet, Noise abatement procedures percentage compliance, Airline cost per operation are the few examples.

Other indicators are used by secondary departmental levels- Declared capacity of airport, length of airfield roads are the few examples.

Some of these indicators can be used only for self-bench marking (change over prior period) and some can be used only for peer and some for both peer as well as self- bench marking.

3.4.2 PARTIAL PRODUCTIVITY MEASURES & TOTAL FACTOR PRODUCTIVITY

The performance measures through the indicators as above are the partial productivity factors, as these are simple quantities or ratios. Partial Productivity Measures (PPM) relates a firm's output to a single input factor. Partial productivity measures are easy to compute, require only limited data, easy to understand and can be misleading- raise productivity in terms of one input, at the expense of reducing the productivity of other inputs.

Airport operation & business model is not uniform across the airports and hence, the use of partial productivity measures on standalone basis may not be appropriate.

Performance evaluation through partial productivity index or measures is very much common in the airport industry to bench mark with other airports or for self-bench marking over a time period. Ratios can provide very useful managerial information about the efficiency: however, they are incapable of accommodating multiple inputs and outputs when accurate objective relative weights for the inputs and outputs are not known. Considering all inputs and outputs in assessing the performance or efficiency is called Total Factor Productivity (TFP). TFP measures by combining all inputs and all outputs to obtain a single ratio helps to avoid imputing gains to one that are really attributable to some other input. However, an attempt to move from partial to total factor productivity measures encounters difficulty such as choosing the inputs and outputs to be considered and the weights to be used in order to obtain a single output to input ratio that results to a simple function like output/input. Methodology like DEA does not require the user to prescribe weights to be attached to each input & output, as in the usual index number approaches, and it also does not require prescribing the functional forms that are needed in statistical regression approaches.

3.4.3 PROPOSED METHODOLOGY

Based on the above, methodology adopted in this research is to evaluate the performance on the effectiveness and efficiency (productive and financial). Effectiveness of services provided is known through the ASQ rating. Hence, appropriate tool is required to be identified for efficiency measures and carry out assessment of the productive efficiency and financial efficiency independently. Also the method that will be used is based on total factor productivity measures.

3.5 CONCLUDING REMARKS

This Chapter identifies that airport's performance is to be measured separately for its financial efficiency and productive efficiency using TFP measures. Effectiveness measurement is done through ASQ rating of services provided.

CHAPTER 4

PRODUCTIVE EFFICIENCY OF AIRPORTS USING DEA

4.1 OVERVIEW

This Chapter will present various methods for efficiency calculations for a unit having multiple inputs and multiple outputs. A brief about DEA methodology is presented with terms used, strengths & weakness, significance of number of units to be considered, importance of selection of input and output parameters. Specific to the present analysis, classification of infrastructure at airports to identify relevant input parameters is explained. The reasons for inclusion of analysis for peak hour traffic at airports are also brought out. The efficiency of the airports under evaluation is carried out with the software.

4.2 VARIOUS METHODOLOGIES FOR CALCULATING THE EFFICIENCY OF UNITS

Ratio analysis does not provide the aggregate measures of efficiency. If a unit is highly efficient on one ratio and low on some other measure of ratio comparative assessment between units becomes difficult as we must know the relative importance weighting to each ratio. Weighting of ratios require formulation of complex decision rules and their justifications. The ratio analysis does not take into account interactions over the full range of inputs and outputs. Simple ratios are partial measures of a multiple outputs and multiple inputs relations. However, the ratios are easy to calculate and understand.

Pure Programming approach uses a sequence of linear programs to construct a transformation frontier and to compute primal and dual relative efficiency relative to the frontier. One of the problems in this approach is that the sample data are enveloped by a maximum production possibility frontier and hence, the entire deviation of an observation from the frontier is attributed to the inefficiency. Also this approach is unable to easily deal with multiple outputs.

Regression Analysis: Significant work has been done using Ordinary Least Square (OLS) to assess comparative performance of units which uses a single input to produce single output. In the single input case the output levels may be regressed in input levels and with the appropriate model, the output level of each unit can be estimated from its input. The biggest problem in regression based studies comes from the need to collapse multiple outputs into a single output measure, and if there are interactions among the outcomes in the production then the estimate for single outcome makes interpretation difficult. Bessent et.al (1982) indicates that major difficulties arise when the OLS is used in multiple output cases because of the implicit impact on outputs having the same input resources.

Deterministic statistical frontier approach uses statistical techniques to estimate a transformation frontier and to estimate primal and dual efficiency relative to the estimated frontier (Afriat 1972; Richmond 1974; Greene 1980). For statistical reasons the sample size should be large. The attempt to specify a distribution for technical efficiency if a production frontier is estimated, specification of such would have to be based on knowledge of the factors that generate inefficiency but this knowledge is rarely available. Estimates of the parameters and of the magnitude of efficiency are not invariant with respect to the specifications of a distribution for the efficiency term. It assumes a deterministic frontier and all deviations from the frontier are attributed to the technical inefficiency

Stochastic frontier approach uses statistical techniques to estimate a transformation frontier and to estimate efficiency relative to the estimated stochastic frontier. A valuable characteristic of this approach is the introduction of a disturbance term representing noise, measurement error and exogenous shocks beyond the control of the production unit. Disadvantages of the approach are that it requires large sample size and structures are imposed on technology as well as distribution of technical inefficiency. This approach also has some difficulties of dealing with multiple outputs.

Data Envelopment Analysis (DEA) is a decision making tool based on linear programming- based technique designed to measure the relative performance of DMUs where the presence of multiple inputs and outputs poses difficulties for comparisons. DEA is initially developed by Charnes, Cooper, Rhodes (1978). Data Envelopment Analysis (DEA) is a non-parametric mathematical programming approach to frontier estimates. Non-parametric approaches have the benefit of not assuming a particular functional form or shape for the frontier. The parametric approach on the other hand requires the shape of the frontier be guessed beforehand by specifying a particular form relating output to input.

DEA does not require the user to prescribe weights to be attached to each input & output, as in the usual index number approaches, and it also does not require prescribing the functional forms that are needed in statistical regression approaches. DEA utilizes techniques such as mathematical programming which can handle number of variables and relations. **Hence, DEA methodology will be used in this study for calculating the productive efficiency.**

4.3 TERMS USED IN DEA & THEIR BRIEF DESCRIPTION

DMU

DMU stands for decision making units. This is an appropriate term than firms. Decision making unit is the designator for units being analyzed in a data envelopment analysis model. Use of this term can be applied to any unit based enterprise that control its mix of inputs and decides on which outputs to produce (Cooper at al.2000)

Productive Efficiency

A measure of a unit's ability to produce outputs from its set of inputs is efficiency. Since the efficiency of a given DMU is measured with respect to other DMUs in the field, the obtained efficiency is always relative. From the standpoint of the efficiency frontier, an enveloped unit's efficiency is related to its radial distance from the frontier.

Constant Returns to Scale (CRS)

Unit operates under constant returns to scale if an increase in inputs results in a proportionate increase in the output levels. If the inputs values for a unit are all doubled, then the unit must produce twice as much output. In a single input and output case, the efficiency frontier reduces to a straight line.

Variable returns to scale (VRS)

An increase in inputs does not result in a proportional change in the outputs. There are two types under this. Increasing Returns to Scale (IRS) and Decreasing Returns to Scale (DRS). A DMU is said to operate at increasing returns to scale (IRS) if a proportionate increase in all of its inputs results in a greater than proportionate increase in its outputs. A unit is said to operate at decreasing returns to scale (DRS) if a proportionate increase in all of its inputs results in a less than proportionate increase in its outputs.

Efficiency Scores

Efficiency is measured on a scale of 0 to 1, where a value of 1 indicates the unit is relatively efficient, and a value less than 1 indicates the unit is inefficient. The efficiency score of a unit will vary according to the factors and DMUs included in the analysis. For example a unit with a score of 0.60 is only 60% efficient as the best performing units in the data set analyzed. The scores are relative (not absolute) to the other units in the data set. (Cooper et al., 2000)

Efficiency Frontier

Efficiency frontier is the frontier represented by the best performing DMUs. The units most efficient at transforming their inputs in to outputs are classified as 100% efficient usually with a value of 1. Any unit not on the frontier with an efficiency rating of less than 1 is considered inefficient (Cooper et al. 2000)

Reference Set or Peer Group

Peer group is the set of efficient units from which an inefficient unit's inefficiency has been determined. These are the group of service units which each **inefficient unit was found to be most directly inefficient**. If the service unit is 100% efficient then this unit is its own ERS or peer. The identification of peers will enable the inefficient units to learn how these peers perform better than them.

Scale efficiency

A unit is said to be scale efficient when its size of operations is optimal so that any modifications on its size will render the unit less efficient.

Production function

Given a set of inputs that produce outputs, the production function defines an optimum relationship for producing the maximal amount of output from the given inputs. The DEA equivalent of the production function is the efficiency frontier which is based on empirical data (inputs and outputs).

Piecewise Linearity

An efficiency frontier is piecewise linear when the underlying production function is approximated through interconnected linear segments. The basic DEA models are all piecewise linear

Targets

The input and output values that would render an inefficient unit relatively efficient

Window analysis

It is the tabular method for examining the changes in the efficiencies of a set of units over time. A set of time periods (1to t) is chosen and the efficiency of each unit (1 to n) is computed separately for each period so that the efficiency of a given unit over each period is treated as a new unit resulting in a total number of tn units.

Weights

Weights are defined within data envelopment analysis model as unknowns that are calculated to determine the efficiency of the units. The efficiency scores are the weighted sum of outputs divided by the weighted sum of inputs for each unit. The weights are calculated to solve the linear program in such a way that each unit is shown in the best possible light. Weights indicate the importance attached to each factor (input/output) in the analysis

4.4 EFFICIENCY MEASURES USING DEA METHODOLOGY

4.4.1 EFFICIENCY CONCEPTS

In the case of a single output and input the efficiency is calculated as the ratio of Output to Input. When we have multiple inputs and outputs and when all the variables have different weightage, the efficiency can be calculated as

$$Efficiency = \frac{U_1Y_{10} + U_2Y_{20} + \cdots + U_rY_{r0}}{V_1X_{10} + V_2X_{20} + \cdots + V_rX_{r0}}$$

Where, U = Output

Y_{r0} = Weightage of Output

V = Input

X_{r0} = Weightage of Input

DEA mathematical model is maximize the efficiency by choosing weights of the variables. This is subject to the constraint that when the same set of weights is applied to all other units that are being compared, no units will be more than 100 % efficient.

DEA accomplishes this without the need to know the relative values of the outputs and inputs that were needed for ratio analysis.

When we evaluate efficiency of service organizations one cannot determine the engineered, optimum or absolute efficient output to input ratio. Consequently we cannot determine whether a service unit is absolutely efficient. However, comparison can be made between the units and determine which unit is more or less efficient than another unit. The difference in efficiency can be due to the technology or process used, how well that process is managed and or the scale or size of the unit.

As DEA has the ability to analyze relative performance when such weights are not available making it particularly effective for service environments where these weights are not available. This attribute of DEA to incorporate multiple inputs and outputs in their natural units without the knowledge of the relative weights makes the DEA uniquely suited for evaluating many service organizations and service providers.

As DEA compares the units considering all resources used and services provided and identifies the most efficient unit, this is a bench marking technique. Hence, the units which are efficient are relatively efficient not strictly efficient. That means no other unit compared in the analysis is clearly operating more efficiently than these units. At the same time, it is possible all the units including these relatively efficient units can be operated more efficiently. Thus efficient units are best existing (not necessarily the best possible) management practice with respect to the efficiency.

Inefficient units are strictly inefficient compared to the efficient units. The inefficiency identified with DEA will tend to overstate, rather than understate the inefficiency present because of linear programming which seeks to maximize the efficiency rating.

DEA measures are units invariant. Meaning by changing the units of measurement, will not change the value of efficiency measures.

4.4.2 SELECTION OF INPUTS AND OUTPUTS

Inputs and outputs are selected based on the following principles:-

- Numerical data are available for each input and output, with data assumed to be positive for all DMUs.
- The inputs and outputs and choice of DMU should reflect an analyst or manager's interest in components that will enter into the relative efficiency evaluation of DMU
- The measurement units of different inputs and outputs need not be congruent. Some may involve number of persons, areas of floor space, money spent etc.

4.4.3 INPUT AND OUTPUT ORIENTATION MODELS

The productive efficiency can be evaluated as an input or output orientation. Input oriented efficiency measure addresses the question by how much can **input quantities be proportionately reduced without changing the output quantities** produced. Whereas the output oriented measure of orientation addresses the question how much the **output can be proportionately increased without changing the input** quantities. The model is selected depending on what is the primary variable- input or output. In this Thesis output orientation measure is adopted since the input i.e the infrastructure already created at the airports cannot be reduced whereas the output quantities are the variables. Also the aim is to find out the productive efficiency to ascertain how much output could have been produced with the available infrastructure compared to other airports. The efficiency scores if less than 100 % will show that the airport has adequate infrastructure to receive more traffic.

4.4.4 RETURNS TO SCALE

Returns to scale relates to whether productive units are of an optimal size or not. If the production unit is of optimal size a marginal increase (decrease) in all the inputs (scale) leads to the same relative increase (decrease) in output. Hence it is called constant returns to scale (CRS) If the output changes relatively more than the input as the size of the production unit is increased it is increasing returns to scale (IRS). In the case of decreasing returns to scale (DRS) the opposite happens. Efficiency can be calculated assuming Constant Returns to Scale (CRS) or Variable Returns to Scale (VRS).

CRS & VRS

The frontier function starts from the origin and with a shape as below in figure

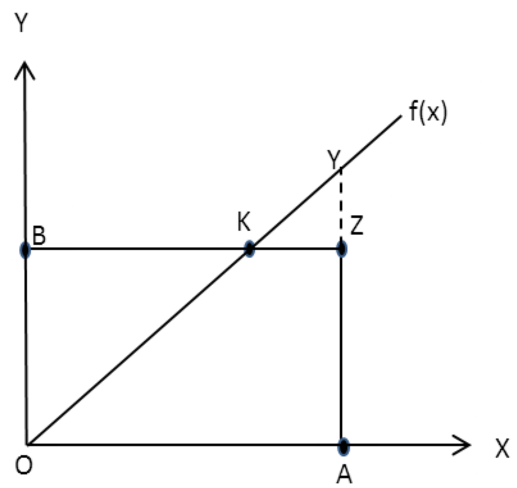

Fig 4.1 Frontier function [30]

For input oriented measure, it is possible to reduce the inputs by KZ and still maintains the output OB.

Technical efficiency = BK/KZ.

For output oriented measure, output can be increased by ZY and with the input remaining constant.

Technical efficiency = AZ/AY.

Efficiency scores with CRS and VRS

Input and output oriented measures will provide the equivalent measure of technical efficiency under CRS, but will be unequal for Variable Returns to Scale as shown in the figure below.

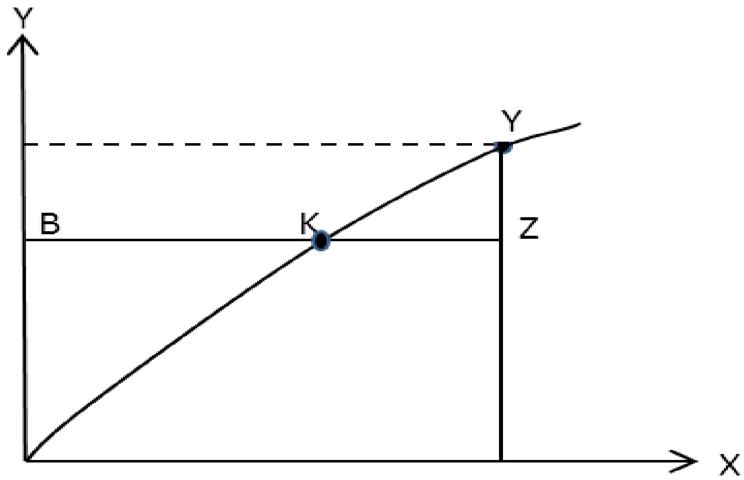

Fig 4.2 CRS and VRS [29]

With CRS, BK/BZ= AZ/AY for any inefficient point Z we choose. VRS can be either decreasing returns to scale or increasing returns to scale. As airports are subject to different competitive environment and with different constraints in production which might prevent them to produce on the most optimum scale it is appropriate to use VRS method.

CRS and VRS frontiers and scale efficiency

Figure 4.3 below explains this concept

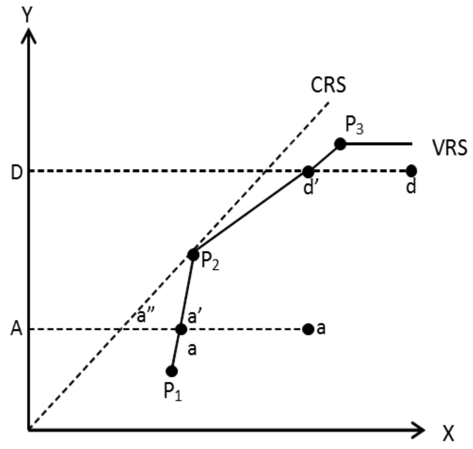

Fig 4.3 Scale Efficiency [30]

The areas to the right of the two frontiers represent the production possibility set (PPS) under CRS and VRS model. Points a & d are inefficient and their input oriented path of projection individualizes referent points a’ and d’ on VRS frontier and a” and d” on CRS frontier. The unique difference between a” and a’ or d’’and d’ is due to control for scale. The ratios Aa”/Aa’ and Dd”/Dd’ represent the measure of scale efficiency while the ratios Aa’/Aa and Dd’/ Dd identify the pure technical efficiency which is exclusively attributable to management effort. CRS measures incorporate scale inefficiency while VRS measures do not.

Point **a** is radially projected on an Increasing Returns of Scale (IRS) facet of the VRS frontier while point **d** is radially projected on a VRS surface where Decreasing Returns to Scale (DRS) hold.

4.4.5 CCR MODEL AND BCC MODEL

Charnes, Cooper & Rhodes proposed a model, hence called CCR, which had an input orientation and assumed Constant Returns to Scale (CRS). Banker, Charnes & Cooper (BCC) proposed a Variable Returns to Scale (VRS) model. CCR model assumes constant returns to scale production possibility set and hence, the efficiency score obtained with **CCR model is called global technical efficiency [29].** BCC model assumes convex combinations of observed DMUs as the production possibility set and hence the efficiency score obtained with **BCC model is called local pure technical efficiency [29]**. If a DMU is fully efficient 100% on both CCR and BCC scores it is operating in the **Most Productive Scale Size** (MPSS). If a DMU has full BCC score but a low CCR score then it is operating locally efficiently but not globally efficient due to scale size of the DMU. Thus the scale efficiency is the ratio of two scores - CCR/BCC.

Slacks

There could be slack in the input or in the output even after coinciding with the efficient frontier. In the figure below, technical efficiency of firm A is OA' / OA and technical efficiency of firm B is OB'/OB. Even though point A' is on the efficient frontier, A can reduce the input by CA' and still produce the same output. This is known as input slack.

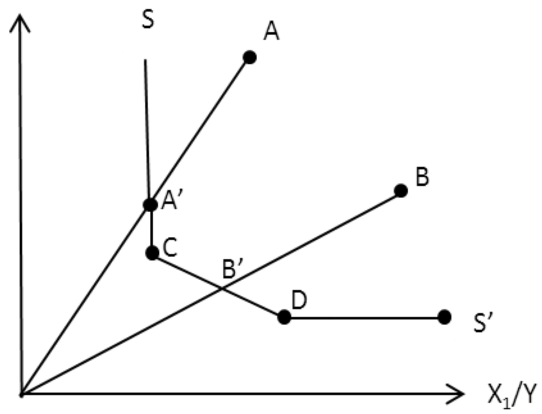

Fig 4.4 Input slack [30]

Figure below explains the output slack. Point P is projected onto point P' which is on the frontier but the output could be increased by an amount P'A without using any more input. Thus there is a slack in this case and it is P’A in output Y_1.

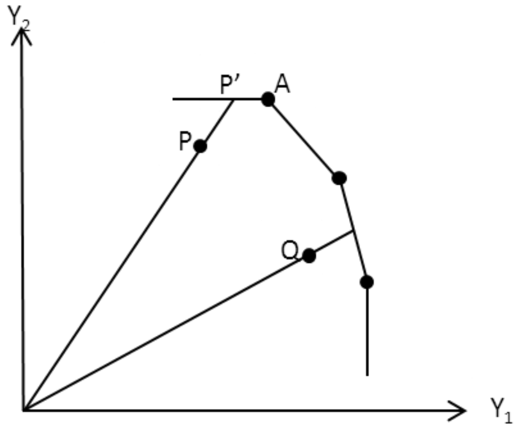

Fig 4.5 Output slack [30]

4.4.6 STRENGTHS & WEAKNESS OF DEA

Strengths

Charnes et. al., (1994) provide the strength of DEA as below

- The focus is on individual DMUs in contrast to population averages
- Each DMU has a single aggregate measure for the utilization of input factors to produce desired outputs
- DEA can simultaneously utilize multiple outputs and multiple inputs with each being stated in different units of measurement
- Adjustments can be made for extraneous variables
- Categorical (dummy) variables can be included
- Computations are value free and do not require specification or knowledge of a priori weights for the inputs and outputs
- There is no restriction on the functional form of the production relationship
- Can accommodate judgement when desired

- DEA can produce specific estimates (targets) for desired changes in inputs and or outputs.
- Results are Pareto optimal
- Focus is on revealed best practice frontiers rather than on central tendency properties of frontiers
- It satisfies strict equity criteria in the relative evaluation of each DMU

Weakness

- – Does not measure absolute efficiency
- – Statistical tests are not applicable
- Number of DMUs > { (m x s), 3 (m+ s)}

Boussofiane et al. 1991; Dyson et al. 2001 suggests rule of thumb to achieve a reasonable level of discrimination is that the number of DMUs should be at least 2 X m X t where m and t are number of inputs and number of outputs

4.5 PRODUCTIVE EFFICIENCY EVALUATION OF AIRPORTS

4.5.1 INPUT AND OUTPUT PARAMETERS

For the purpose of DEA analysis, input and output parameters of the airport are to be chosen carefully which are relevant to evaluate the productive efficiency. If an airport is considered similar to a manufacturing industry, the inputs are the infrastructure, cost and resources. The outputs are the number of passengers, number of aircraft movement, cargo quantity handled and revenue. Since the DEA methodology is used here for the productive efficiency of the airport and the aim is to separate it from financial performance, the financial parameters are not considered in this analysis and analyzed in the next chapter.

The input parameters of airports, which are the infrastructure to handle the passengers, cargo and aircraft operations, are

Inputs

- Passenger terminal building
- Check-in counters
- Aircraft stands (Apron)
- Passenger Boarding Bridges
- Gates
- Runways and taxiways system
- Cargo terminal building
- Car parking capacity, arrival conveyor length, number of escalators and elevators

Infrastructure at the airports can be classified into three categories.

The first category is the basic facilities without which an airport operation cannot take place. Under this category are the passenger terminal building, apron stands, runway, check-in counters and cargo terminal for cargo movement. Hence, the area or quantity of these infrastructures is relevant for the performance assessment. The unit for the passenger terminal building in sq.m. will be relevant; similarly cargo terminal building area. The quantity of check in counters is relevant. For the apron stands it is relevant to identify the numbers than the area, since the area depends on the type of aircrafts the airport handles.

In the second category is the infrastructure like boarding bridges, boarding gates, car parking capacity, conveyor length or number of escalators/ elevators etc. These facilitate the passenger movement; the effectiveness of these facilities can be seen from the passenger satisfaction survey (ASQ). Hence, these need not be considered as a part of measuring the productive efficiency of an airport. Also the quantity of these facilities depends on the terminal building configuration and many other aspects. It is very difficult to compare two airports on these facilities.

In the third category is the infrastructure like number of runways, number of taxiways, width & length of runways/ taxiways etc. The requirement of number of runways for example will be dictated by the number of aircraft movement, particularly the peak hour traffic, as single runway cannot handle more than certain peak hour traffic number depending on certain operational factors. Similarly the width of the runway / taxiway depends on the Code of the airport (type of aircraft) and the number of taxiways depends on the airfield layout. Hence, such infrastructure is not relevant when we assess & compare the airports which handle very much varying aircraft configurations and number of movements. Also most of these requirements are dictated by the regulatory requirement.

It is also pertinent to note that the inputs like employee number at an airport, depends on the operation strategy. One strategy could be to outsource certain functions at the airport, for example the ground handling services, which includes check-in process, handling of bags from & to aircraft. Similarly the cost or expenditure at an airport should be considered only when it is confirmed that these are only for passenger and cargo operations of the airport. Some airports carry out many commercial activities including consultancy services to other airports. Hence, unless such details are known these inputs if considered will lead to misleading results.

Since in this research the productive efficiency is evaluated for infrastructure only the infrastructure as in first category as above is considered.

Outputs

The outputs at an airport that are produced based on the infrastructure provided are

- Passenger Numbers
- Aircraft movements
- Number of airlines operating
- Number of destinations served
- Cargo volume

Hence, in this research the input and output parameters considered are

Inputs falling under category 1

- Area of passenger terminal building
- Number of check-in counters
- Number of apron stands
- Area of cargo terminal building

Outputs

- Annual Passenger Numbers
- Annual Aircraft movement
- Annual Cargo volume
- Number of airlines operating
- Number of destinations served

4.5.2 SAMPLE SIZE FOR THE EVALUATION

4.5.2.1 MINIMUM NUMBER OF UNITS

In DEA methodology, if the number of Decision Making Units is less than the combined number of inputs and outputs a large portion of the DMUs will be identified as efficient and efficiency discrimination among DMUs is lost. Hence, it is suggested that the number of units exceeds the sum of input and output variables by several times. As in statistics or other empirically oriented methodologies, there is a problem involving degrees of freedom, which is compounded in DEA because of its **orientation to relative efficiency.** Rough rule of thumb which can provide guidance is

Number of units > maximum {3 (m + s), (m X s)}. Where, m and s are number of inputs and outputs parameters.

In this research we have maximum of 7 variables (input+ output) and hence, 21 units are required for evaluation.

4.5.2.2 RATIONALE' FOR THE AIRPORTS CHOSEN

Indian Airports

The analysis aim is to evaluate the performance of 7 airports namely Chennai, Kolkata (both AAI airports), Mumbai, Delhi, Hyderabad, Cochin and Bangalore (all PPP airports). Also included in the DEA analysis are the other major airports as identified by AERA. These airports are Ahmedabad, Calicut, Trivandrum, Goa and Pune. In addition to these 12 airports included are Amritsar, Jaipur, Srinagar, Coimbatore, Guwahati (all international airports).

Overseas Airports

In order to compare the Indian airports and also to increase the numbers of DMUs for the analysis, 23 overseas airports are included. Also as DEA identifies peers for the airports of which the efficiency is less than 100 %, it would be appropriate to compare with overseas airports for bench marking. Another reason is that in respect of passenger volume in the year 2010-11, the total passenger handled in all the Indian airports is 143 million. Out of which the 17 Indian airports considered for analysis handled 123 million. Among these 17 airports, Delhi (30) & Mumbai (29) put together handled 59 million. To compare Delhi there is only one airport that is Mumbai. After Mumbai the next highest traffic airport is Chennai which handled only 12 million, followed by Bangalore, Kolkata, Hyderabad and Cochin. Hence, if restricted to only Indian airports, DEA being a bench marking tool, comparability will be difficult. With inclusion of overseas airports we get comparability in terms of number of passengers handled, passenger mix (international/ domestic) also the peak hour traffic. Hence, in the performance evaluation, 23 overseas airports are also included. The passenger traffic at these airports has wide variation and also the airports' ASQ score is more than 3.5, except three airports which did not participate in the survey.

4.5.2.3 SENSITIVITY ANALYSIS OF THE SCORES

In order to check the sensitivity of the performance scores obtained with 40 airports, performance scores with 27 airports out of the 40 which handled more than 5 million passengers per annum and only 17 Indian airports out of the 40 are also evaluated. To summarize the productive efficiency has been carried out with the following groups of airports

- Group 1- 40 airports (17 Indian airports + 23 overseas airports)
- Group 2- 27 Airports that handled more than 5 million passengers per annum (6 Indian airports+ 21 overseas airports)

- Group 3- 17 Indian Airports

4.6 PRODUCTIVE EFFICIENCY BASED ON ANNUAL BASIS

An airport operates for the purpose of passengers and cargo movements and the infrastructure created are to meet these requirements. The annual basis analysis is essential because the performance of airports including passengers and cargo or passenger terminals is published in terms of their annual capacity (Example 50 million passengers per annum) Similarly the cargo capacity of an airport is published on annual capacity that it can handle. Hence, it is appropriate to evaluate the airport's productivity with reference to the annual capacities. This is the way all the previous research have been conducted and analyzed.

Output parameters considered are

- number of passengers handled in the year,
- number of aircraft movements in the year,
- quantity of cargo handled in tons.
- number of airlines operating out of the airport
- number of destinations served from the airport

The input parameters considered are

- Area passenger terminal building
- Area of the cargo terminal building.

This measure provides the productive efficiency of the airport in a year. The very purpose of an airport is to facilitate the passenger movement and the cargo movement. This is achieved through creation of infrastructure like passenger terminal building, cargo terminal building, runway & taxiway system and aircraft parking bays and other services like utilities etc. As already mentioned the infrastructure that are essential for operations and that are common among the airports are considered for inputs i.e. passenger terminal building area and cargo terminal building area, to handle passengers and cargo respectively. On the output parameter in addition to the passenger numbers, cargo quantity and number of aircraft movements, the number of airlines and number of destinations served has been considered. The last two variables are included because if an airport wants to improve its passenger numbers in addition to normal growth of the traffic on the same sectors which the airlines are currently operating, its number of destinations served must increase as well as the number of airlines operating out of the airport must increase. Without the increase of these two parameters the airport traffic cannot grow. Similarly the number of passengers and aircraft movement may look alike, but these numbers together will show the load factor of the aircrafts.

Master data of **40 airports for the year 2010-11** considered for the DEA analysis on annual basis is in **Appendix 3.**

Correlation between input and output variables

There is a requirement in applying DEA that input and output variables should be positively correlated (Luo and Donthu 2005). The descriptive statistics of the data including the correlation among the variables are calculated and presented in table 4.1 below, which shows that the variables are positively correlated.

Table 4.1- Descriptive statistics and Correlation matrix for annual basis

DESCRIPTIVE STATISTICS –ANNUAL BASIS- 2010-11							
Statistics	PAX in Million	ATM	Cargo in Tons	Airlines	Destinations	Area of PAX Terminal	Area of Cargo Terminal
Mean	20.66	173290	751086	44.9	94	314127	116048
SD	18.66	135950	1033240	36.9	75.36	359762	160268
Min	0.765	9018	2016	3	4	8655	1000
Max	73.94	517585	4200000	150	275	1444474	660572
CORRELATION BETWEEN OUTPUT & INPUT VARIBALES ANNUAL BASIS- 2010-11							
Variables	PAX in Millio	ATM	Cargo in Tons	Airlines	Destinations	Area of PAX Terminal	Area of Cargo Terminal
PAX	1						
ATM	0.927	1					
Cargo	0.756	0.626	1				
Airlines	0.86	0.795	0.717	1			
Destinatio	0.878	0.877	0.653	0.93	1		
Area of PAX Terminal	0.867	0.748	0.791	0.891	0.82	1	
Area of Cargo Terminal	0.762	0.688	0.775	0.684	0.682	0.665	1

4.6 PRODUCTIVE EFFICIENCY BASED ON PEAK HOUR BASIS

The second analysis is based on peak hour passengers handled and ATM handled at the airports. As already mentioned, airports are subject to peak demands. The productive efficiency is required to be measured with reference to the peak hour traffic at the airport. This will enable to understand the performance of the airport during the peak hours. The efficiency with peak hour traffic is the efficiency of only the passenger terminal building. Airport Capacity is primarily determined by the capacity during the course of day and number of flights that can be scheduled to take off and land and also number of passengers that can be handled. Airports should have sufficient capacity to cope with different peaks.

The trigger for additional capacity is not triggered through annual capacity initially but triggered through peak hour capacity & anticipated additional peak hour flows. Annual capacity does not dictate the terminal size. There is a limited ability to spread peak of passengers using the airport, the airport company will continue to make a greater and more efficient use of existing facilities by increasing the number of peak hours.

Approach adopted by IATA for terminal capacity planning is to assess the design capacity against the demand in an hour known as Standard busy hour Standard busy rate defined as 31^{st} busiest hour in a year. IATA level of service space standards for airport passengers terminals based on busy hours is as below in table below

Table 4.2 Space Standards for level of service. (Values are in Sq.m. per Passenger)

Sl. no.	Level of Service	A	B	C	D	E
1	Check in queue	1.8	1.6	1.4	1.2	1.0
2	Waiting/ Circulate area	2.7	2.3	1.9	1.5	1.0
3	Hold Room	1.4	1.2	1.0	0.8	0.6
4	Baggage clearing area	2.0	1.8	1.6	1.4	1.2
5	GOVT Inspection	1.4	1.2	1.0	0.8	0.6

Level A is excellent and Level D is desirably the lowest level achieved in peak hour operations. Level F is the point of system break down / congestion. Most airports use level C for planning purpose.

Factors affecting hourly capacity of runway are runway/taxiway layout, taxing system, weather, aircraft mix, runway occupancy time, ATC procedures, ratio of arrival departure, noise abatement procedure and separation distance between aircrafts in air space depending on aircraft mix.

During the planning & designing of airport passenger terminals the peak hour air traffic movement and peak hour passenger traffic are estimated and the size of the terminal and the number of passenger processing counters like check-in and number of aircraft stands are decided. Hence, it is appropriate to measure the productivity during the peak hour traffic and compare between the airports to know how an efficient airport is managing the traffic with less or similar area and infrastructure. It could be technology or better trained people. The productive efficiency during peak hour traffic has not been analyzed so far in the previous research. The input and output parameters for the peak hour basis is different from annual basis since the purpose is only to evaluate the productive efficiency of passenger terminal and these are as mentioned below

Input parameters are- Area of Passenger Terminal building, Number of check-in counters, Number of apron bays

Output parameters are Peak hour passenger numbers & Peak hour ATM numbers.

Master data of **40 airports** considered for the DEA analysis on **peak hour traffic basis is** in **Appendix 4.** The descriptive statistics of the data including the correlation among the variables are calculated and is in **table 4.3 below** which shows that the variables are positively correlated.

Table 4.3 Descriptive statistics & correlation matrix for peak hour basis

DESCRIPTIVE STATISTICS –PEAK HOUR TRAFFIC					
Statistics	Peak Hour PAX	Peak Hour ATM	Check-in counters	Apron bays	Area of PAX terminal
Mean	6402	39.2	170.8	83.9	314127
SD	5357	29	147	73	359763
Min	600	5	14	8	8655
Max	18571	102	492	328	1444474

CORRELATION BETWEEN OUTPUT & INPUT VARIBALES PEAK HOUR TRAFFIC					
Variables	Peak Hour PAX	Peak Hour ATM	Check-in counters	Apron bays	Area of PAX terminal
Peak Hour PAX	1				
Peak Hour ATM	0.948	1			
Check-in counters	0.926	0.852	1		
Apron bays	0.936	0.929	0.845	1	
Area of PAX Terminal	0.88	0.758	0.878	0.833	1

4.8 SOFTWARE USED FOR DEA METHODOLOGY

In this research the DEA software used is from “Centre for Efficiency and Productivity Analysis”, University of New England **[29].** The software can be downloaded free from www. Une.edu.au. This software is user friendly and does not have restrictions in terms of maximum number of DMUs or the number of variables. As already mentioned output orientation and VRS model will be used to get the following results for the DMUs

- Pure Technical Efficiency (vrste)
- Global Technical Efficiency (crste)
- Scale Efficiency (crste/vrste)
- Peers and its weight for the DMUs which have a score less than 100 %

- Input targets and output targets for the DMUs which have score less than 100 %
- Input slacks and output slacks if any for the DMUs which have scored less than 100%

4.9 EFFICIENCY SCORES

4.9.1 ON ANNUAL BASIS WITH 40 AIRPORTS

The data of 40 airports on annual basis is entered into the software and the output from the software is in **Appendix 5**. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in table 4.4, 4.5 and figure 4.6 below

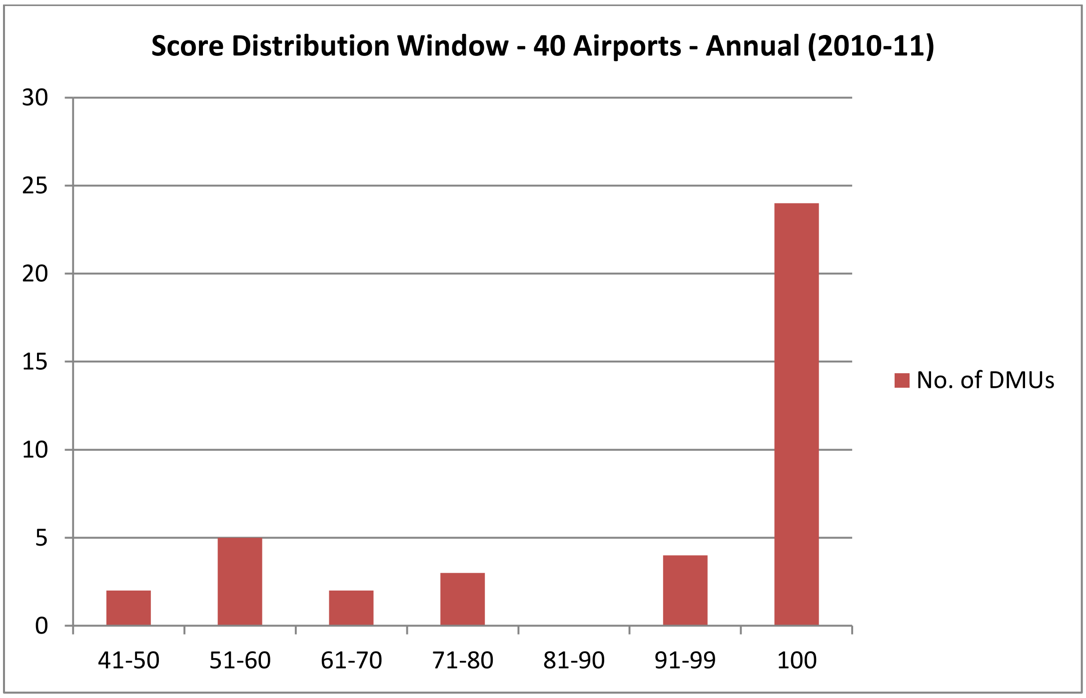

Fig 4.6 Score distribution window for 40 airports- annual basis

Table 4.4 Efficiency scores of 40 Airports on annual basis			
Airport	Pure Technical Efficiency	Airport	Scale Efficiency
Changi	1	Chennai	1
Chennai	1	Goa	1
Goa	1	Coimbatore	1
Guwahati	1	Guwahati	1
Ahmedabad	1	Ahmedabad	1
Incheon	1	Incheon	1
Dubai	1	Mumbai	1
Mumbai	1	Jaipur	1
Beijing	1	Srinagar	1
Munich	1	Amritsar	1
Pune	1	Pune	1
Hong Kong	1	Male'	1
Frankfurt	1	Indianapolis	1
SGI (Istanbul)	1	Austin Bergstrom	0.998
Brazil (Sao Paulo)	1	Taiwan Taoyuan	0.938
Male'	1	Hong Kong	0.916
Sydney	1	Ottawa	0.845
Indianapolis	1	Bangalore	0.804
Ottawa	1	Baiyun China	0.802
Austin Bergstrom	1	Calicut	0.76
Vancouver Intl	1	Narita Intl	0.753
Baiyun China	1	Changi	0.749
Stansted	1	Kolkata	0.727
Manchester	1	Dubai	0.669
Bangkok	0.996	Vancouver Intl	0.664
Pu Dong Airport	0.944	Pu Dong Airport	0.654
Kuala Lumpur	0.921	Trivandrum	0.585
Delhi	0.911	Brazil (Sao Paulo)	0.579
Kolkata	0.803	Kuala Lumpur	0.578
Taiwan Taoyuan	0.783	Sydney	0.562
Bangalore	0.776	Stansted	0.558
Jaipur	0.721	Hyderabad	0.52
Cochin	0.696	Delhi	0.515
Narita Intl	0.684	Cochin	0.487
Hyderabad	0.587	Frankfurt	0.445
Coimbatore	0.568	Bangkok	0.374
Calicut	0.533	SGI (Istanbul)	0.345
Trivandrum	0.508	Beijing	0.341
Amritsar	0.458	Munich	0.313
Srinagar	0.433	Manchester	0.228

Table 4.5 Descriptive statistics of efficiency scores of 40 airports on annual basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.433	Min	0.228
Max	1	Max	1
Mean	0.88	Mean	0.74
SD	0.18	SD	0.24
No. of Efficient units	24	No. of Efficient units	13
Total no. of units	40	Total no. of units	40

The peers for the airports which have scored less than 100 % are as in table 4.6 below. The result shows that Mumbai has appeared 9 times as peer, followed by Goa 8 times and followed by Guwahati 7 times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.6 Peers for 40 airports on annual basis

40 Airports- Annual - 2010-11- Peers	
Airport	**Peers**
Hyderabad	SGI, **Ottawa**, Manchester, Goa, Mumbai, Stansted
Delhi	Changi, Dubai, SGI, **Sydney**, Manchester
Cochin	**Guwahati**, Mumbai
Bangkok	Mumbai, Munich, Frankfurt, Hong Kong
Trivandrum	Mumbai, Goa
Calicut	Goa, Guwahati, Mumbai, Manchester
Coimbatore	Pune, Goa, Guwahati
Kolkata	**Mumbai**, Stansted, Brazil, Guwahati
Bangalore	Goa, **Mumbai,** Guwahati
Jaipur	Goa, Guwahati, Ahmedabad
Kuala Lampur	Changi, Sydney, Munich, Mumbai, Baiyun China
Srinagar	Goa, Guwahati
Amritsar	Ahmedabad, Goa
Narita Intl	Baiyun China, Incheon, Dubai, Hong Kong
Pu Dong Airport	Hong Kong, Frankfurt,
Taiwan Taoyuan	Incheon, Mumbai, Hong Kong, Chennai,

4.9.2 ON ANNUAL BASIS WITH 27 AIRPORTS

The data of 27 airports on annual basis is entered into the software and the software output is in **Appendix 6**. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in fig 4.7 and tables 4.7 and 4.8

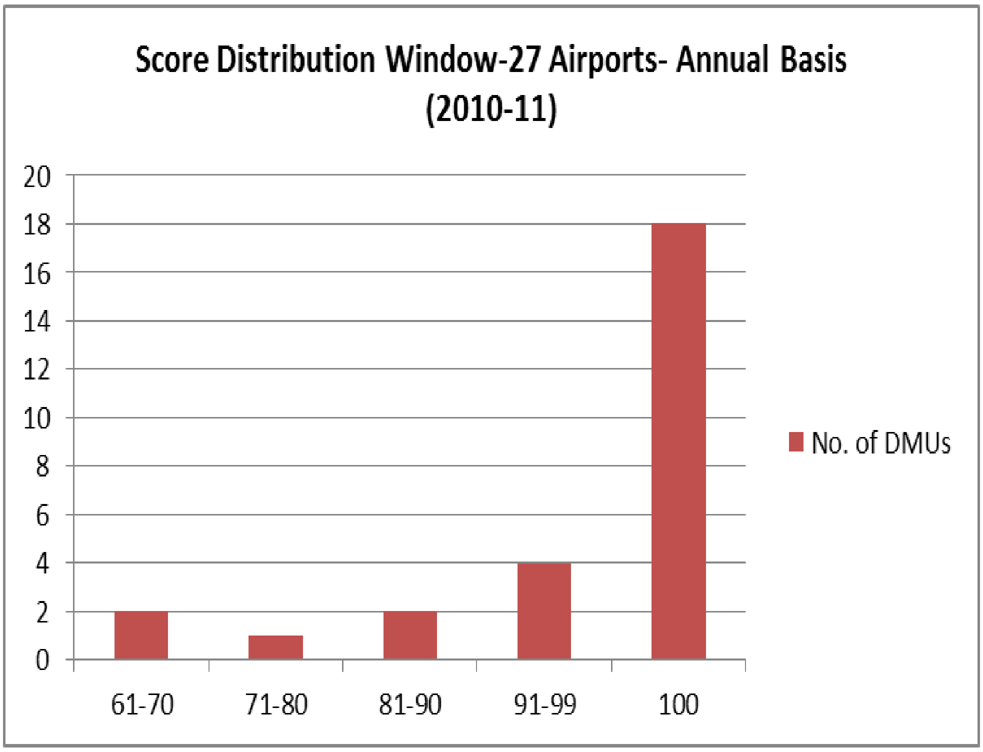

Fig 4.7 Score distribution window for 27 airports - annual basis

Table 4.7- Efficiency scores of 27 airports on annual basis

Efficiency scores of Group 2- 27 Airports Annual 2010-11			
Airport	**Pure Technical efficiency**	**Airport**	**Scale Efficiency**
Changi	1	Changi	1
Chennai	1	Chennai	1
Incheon	1	Incheon	1
Mumbai	1	Mumbai	1
SGI	1	SGI	1
Sydney	1	Sydney	1
Indianapolis	1	Indianapolis	1
Austin Bergstrom	1	Austin Bergstrom	1
Stansted	1	Stansted	1
Manchester	1	Manchester	1
Dubai	1	Kolkata	0.99
Hong Kong	1	Hyderabad	0.989
Baiyun China	1	Bangalore	0.97
Vancouver Intl	1	Kuala Lumpur	0.95
Sao Paulo (Brazil)	1	Taiwan Taoyuan	0.938
Munich	1	Dubai	0.925
Frankfurt	1	Hong Kong	0.916
Beijing	1	Baiyun China	0.913
Bangkok	0.996	Delhi	0.893
Pu Dong Airport	0.944	Vancouver Intl	0.871
Kuala Lumpur	0.921	Sao Paulo (Brazil)	0.833
Delhi	0.911	Munich	0.824
Bangalore	0.853	Narita Intl	0.753
Kolkata	0.836	Pu Dong Airport	0.654
Taiwan Taoyuan	0.783	Frankfurt	0.445
Narita Intl	0.684	Beijing	0.393
Hyderabad	0.622	Bangkok	0.374

Table 4.8 Descriptive statistics of efficiency scores 27 airports on annual basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.622	Min	0.374
Max	1	Max	1
Mean	0.946	Mean	0.875
SD	0.10	SD	0.19
No. of Efficient units	18	No. of Efficient units	10
Total no. of units	27	Total no. of units	27

The peers for the airports which have scored less than 100 % are as in table 4.9 below. The result shows that Mumbai has appeared 5 times as peer, followed by Chennai 4times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.9 Peers for 27 airports on annual basis

Hyderabad	SGI, **Chennai,** Austin, Manchester, Stansted, Mumbai
Delhi	Dubai, SGI, **Sydney**, Changi, Manchester
Bangkok	Mumbai, Hong Kong, Munich, Frankfurt
Kolkata	Mumbai, **Chennai**
Bangalore	Mumbai, **Chennai**
Kuala Lumpur	Changi, Sydney, Munich, Baiyun
Narita Intl	Incheon, Dubai, Hong Kong
Pu Dong Airport	Frankfurt
Taiwan Taoyuan	Chennai, Mumbai, Hong Kong, Incheon

4.9.3 ANNUAL BASIS WITH 17 AIRPORTS

The data of 17 airports on annual basis is entered into the software and the software output is in Appendix 7. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in figure 4.8 and tables 4.10 and 4.11 below

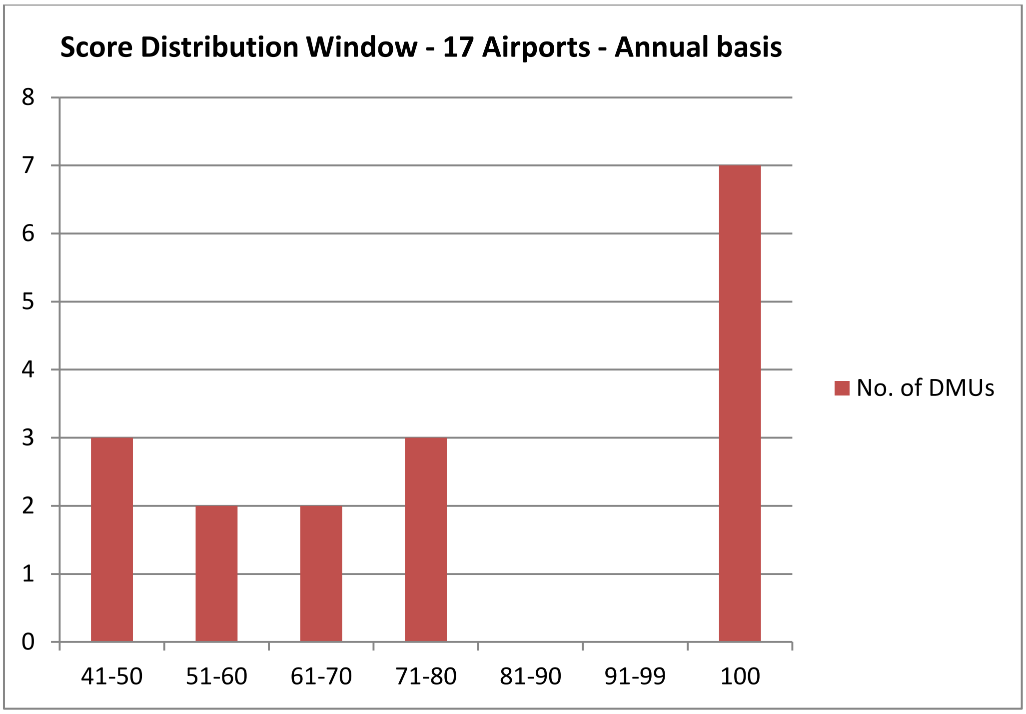

Fig 4.8 Score Distribution Window for 17 Airports - Annual basis

Table 4.10 Efficiency scores of 17 airports on annual basis

Efficiency scores of Group 3- 17 Airports Annual 2010-11			
Airport	**Pure Technical Efficiency**	**Airport**	**Scale Efficiency**
Delhi	1	Chennai	1
Chennai	1	Goa	1
Goa	1	Coimbatore	1
Guwahati	1	Guwahati	1
Ahmedabad	1	Ahmedabad	1
Mumbai	1	Mumbai	1
Pune	1	Jaipur	1
Kolkata	0.806	Srinagar	1
Bangalore	0.776	Amritsar	1
Jaipur	0.721	Pune	1
Hyderabad	0.696	Bangalore	0.804
Cochin	0.696	Calicut	0.789
Coimbatore	0.568	Kolkata	0.725
Calicut	0.538	Trivandrum	0.62
Trivandrum	0.508	Delhi	0.497
Amritsar	0.458	Cochin	0.487
Srinagar	0.433	Hyderabad	0.439

Table 4.11 Descriptive statistics of the efficiency scores of 17 airports on annual basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.433	Min	0.439
Max	1	Max	1
Mean	0.78	Mean	0.84
SD	0.21	SD	0.21
No. of Efficient units	7	No. of Efficient units	10
Total no. of units	17	Total no. of units	17

The peers for the airports which have scored less than 100 % are as in table 4.12 below. The result shows that Goa has appeared 8 times as peer, followed by Guwahati and Mumbai 6 times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.12 Peers for 17 Airports on annual basis

Airport	**Peers**
Hyderabad	Delhi, **Ahmedabad**, Mumbai
Cochin	Mumbai, **Guwahati**
Trivandrum	Mumbai, Goa
Calicut	Goa, Ahmedabad, Mumbai
Coimbatore	Guwahati, Pune, Goa
Kolkata	Goa, **Mumbai,** Guwahati
Bangalore	**Mumbai**, Guwahati, Goa
Jaipur	Ahmedabad, Goa, Guwahati
Srinagar	Guwahati, Goa
Amritsar	Goa, Ahmedabad

4.9.4 ON PEAK HOUR BASIS WITH 40 AIRPORTS

The data of 40 airports on peak hour basis is entered into the software and the software output is in Appendix 8. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in figure 4.9 and tables 4.13 and 4.14 below

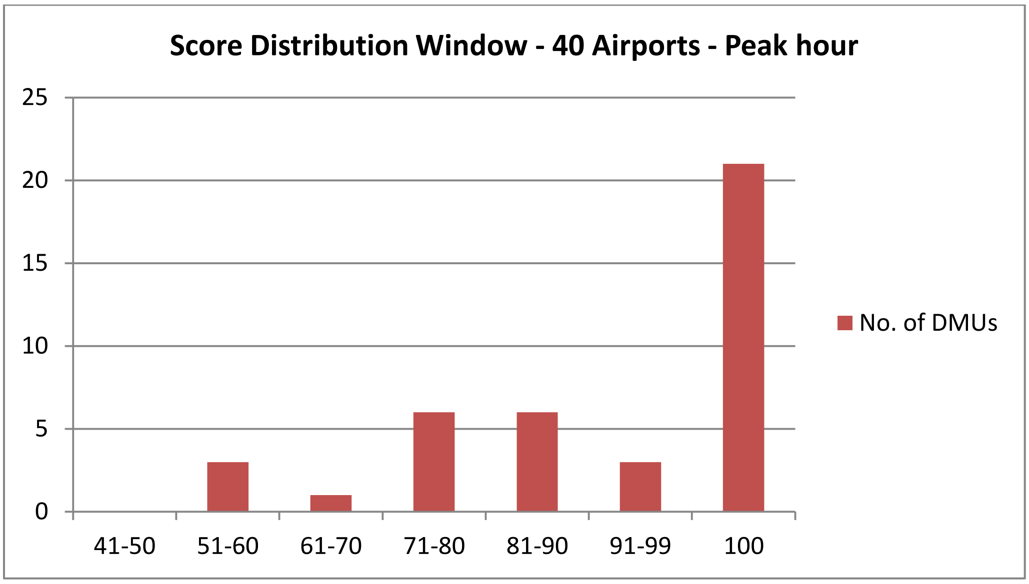

Fig 4.9- Score distribution for 40 airports peak hour basis

Table 4.13- Descriptive statistics of the efficiency scores of 40 airports on peak hour basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.558	Min	0.689
Max	1	Max	1
Mean	0.89	Mean	0.91
SD	0.14	SD	0.10
No. of Efficient units	21	No. of Efficient units	8
Total no. of units	40	Total no. of units	40

Table 4.14 – Efficiency scores of 40 airports on peak hour basis

Efficiency scores of Group 1 - 40 Airports Peak hour basis - 2010-11			
Airport	**Pure Technical**	**Airport**	**Scale Efficiency**
Chennai	1	Chennai	1
Goa	1	Goa	1
Coimbatore	1	Guwahati	1
Guwahati	1	Pune	1
Mumbai	1	Ottawa	1
Beijing	1	Baiyun China	1
Munich	1	Pu Dong Airport	1
Srinagar	1	Taiwan Taoyuan	1
Pune	1	Amritsar	0.998
Hong Kong	1	Bangalore	0.995
Frankfurt	1	Calicut	0.995
Sao Paulo (Brazil)	1	Hyderabad	0.991
Sydney	1	Jaipur	0.988
Indianapolis	1	Trivandrum	0.981
Ottawa	1	SGI	0.979
Austin Bergstrom	1	Ahmedabad	0.977
Vancouver Intl	1	Srinagar	0.971
Narita Intl	1	Austin Bergstrom	0.968
Baiyun China	1	Indianapolis	0.957
Pu Dong Airport	1	Male'	0.956
Taiwan Taoyuan	1	Sydney	0.955
SGI	0.946	Cochin	0.947
Incheon	0.935	Mumbai	0.921
Manchester	0.904	Delhi	0.921
Mean		Manchester	0.91
Changi	0.89	Stansted	0.91
Delhi	0.856	Mean	
Stansted	0.842	Coimbatore	0.872
Dubai	0.84	Narita Intl	0.863
Male'	0.835	Kuala Lumpur	0.855
Bangalore	0.803	Hong Kong	0.832
Bangkok	0.788	Kolkata	0.827
Calicut	0.771	Sao Paulo	0.81
Kolkata	0.758	Bangkok	0.791
Kuala Lumpur	0.758	Frankfurt	0.774
Cochin	0.73	Changi	0.747
Hyderabad	0.709	Dubai	0.745
Ahmedabad	0.642	Vancouver Intl	0.726
Jaipur	0.577	Incheon	0.707
Amritsar	0.566	Beijing	0.696
Trivandrum	0.558	Munich	0.689

The peers for the airports which have scored less than 100 % are as in table 4.15 below. The result shows that Goa has appeared 11times as peer, followed by Sydney 10 times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.15- Peers for 40 airports on peak hour basis

Hyderabad	Sydney, **Ottawa,** Taiwan, Goa
Delhi	**Sydney,** Narita, Baiyun, Taiwan
Changi	Frankfurt, Hong Kong
Cochin	Taiwan, Sydney, **Goa**
Bangkok	Sydney, Baiyun, Hong Kong
Trivandrum	Baiyun, Taiwan, Goa, Ottawa, Sydney
Calicut	Goa, Chennai, Guwahati
Kolkata	Brazil, Ottawa, Vancouver, **Goa**
Ahmedabad	Goa, Taiwan, Sydney, Baiyun
Incheon	Frankfurt, Hong Kong, Baiyun
Dubai	Frankfurt, Hong Kong, Narita
Bangalore	**Ottawa**, Baiyun, Chennai, Pune
Jaipur	Goa, Chennai, Guwahati
Kuala Lumpur	Baiyun, Frankfurt, Hong Kong, Sydney
Amritsar	Ottawa, Taiwan, Goa, Pune
SGI	Taiwan, Ottawa, Sydney, Goa
Male'	Guwahati
Stansted	Sydney, Brazil, Goa, Mumbai, Chennai
Manchester	Sydney, Pu Dong, Ottawa

4.9.5 ON PEAK HOUR BASIS WITH 27 AIRPORTS

The data for 27 airports on peak hour basis is entered into the software and the output is Appendix 9. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in figure 4.10 and tables 4.16 and 4.17 below

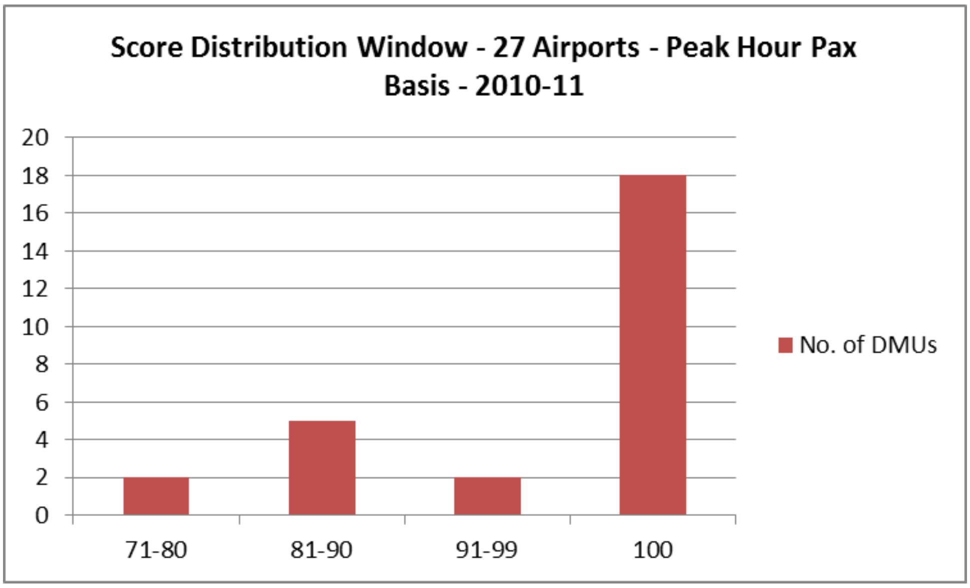

Fig 4.10 Score distribution window for 27 airports peak hour basis

Table 4.16 Descriptive statistics of the efficiency scores for 27 airports on peak hour basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.758	Min	0.696
Max	1	Max	1
Mean	0.953	Mean	0.912
SD	0.07	SD	0.09
No. of Efficient units	18	No. of Efficient units	9
Total no. of units	27	Total no. of units	27

Table 4.17 Efficiency scores of 27 airports on peak hour basis

Efficiency scores of Group 2- 27 Airports - Peak Hour Traffic 2010-11			
Airport	**Pure Technical efficiency**	**Airport**	**Scale Efficiency**
Chennai	1	Chennai	1
Mumbai	1	Mumbai	1
Sao Paulo (Brazil)	1	Sao Paulo (Brazil)	1
Sydney	1	Sydney	1
Indianapolis	1	Indianapolis	1
Austin Bergstrom	1	Austin Bergstrom	1
Baiyun China	1	Baiyun China	1
Pu Dong Airport	1	Pu Dong Airport	1
Taiwan Taoyuan	1	Taiwan Taoyuan	1
Vancouver Intl	1	Stansted	0.989
SGI	1	Vancouver Intl	0.978
Hong Kong	1	SGI	0.971
Narita Intl	1	Manchester	0.956
Kolkata	1	Delhi	0.931
Bangalore	1	Hong Kong	0.927
Frankfurt	1	Kuala Lumpur	0.9
Munich	1	Hyderabad	0.877
Beijing	1	Narita Intl	0.863
Incheon	0.935	Changi	0.855
Manchester	0.913	Bangkok	0.845
Hyderabad	0.9	Kolkata	0.841
Changi	0.89	Bangalore	0.832
Stansted	0.858	Incheon	0.823
Delhi	0.856	Frankfurt	0.807
Dubai	0.84	Munich	0.773
Bangkok	0.788	Dubai	0.748
Kuala Lumpur	0.758	Beijing	0.696

The peers for the airports which have scored less than 100 % are as in table 4.18 below. The result shows that Sydney and Hong Kong have appeared 5 times as peer, followed by Frankfurt and Baiyun 4 times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.18 Peer for 27 airports on peak hour basis

Hyderabad	SGI, Indianapolis, Chennai, **Bangalore**
Delhi	Narita, Baiyun, **Sydney,** Taiwan
Changi	Frankfurt, Hong Kong
Bangkok	Baiyun, Hong Kong, Sydney
Incheon	Frankfurt, Hong Kong, Baiyun
Dubai	Narita, SGI, Hong Kong
Kuala Lumpur	Sydney, Frankfurt, Baiyun, Hong Kong
Stansted	Kolkata, Sao Polo, Sydney, Chennai
Manchester	Sydney, Pu Dong, Chennai

4.9.6 ON PEAK HOUR BASIS WITH 17 AIRPORTS

The data of 17 airports on peak hour basis is entered into the software and the output is in Appendix 10. The score distribution window, efficiency scores and descriptive statistics of the efficiency scores are extracted and presented in figure 4.11and tables 4.19 and 4.20 below

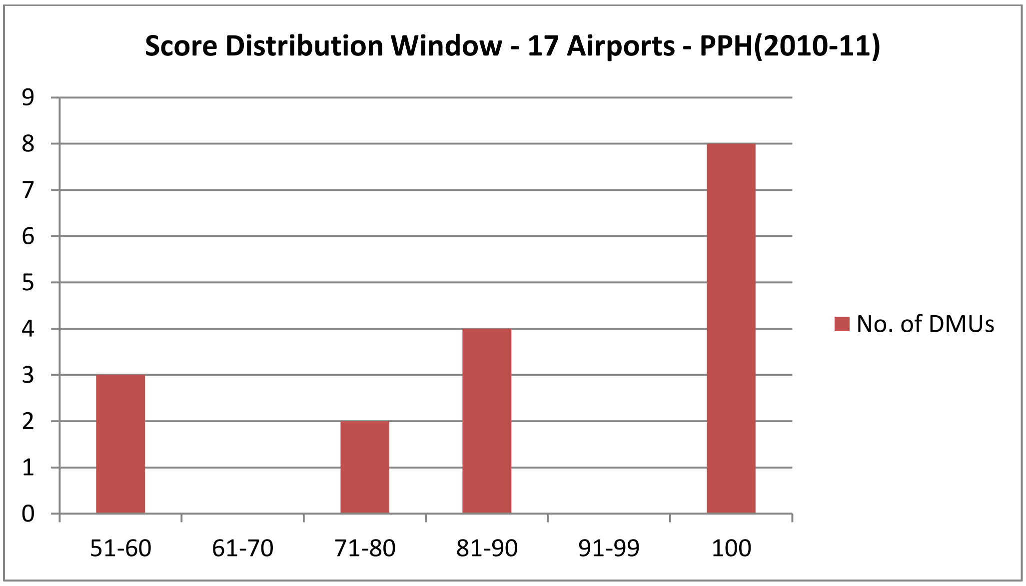

Fig 4.11- Score distribution window for 17 airports - peak hour basis

Table 4.19 Descriptive statistics of the efficiency scores of 17 airports on peak hour basis

Descriptive Statistics of Pure Technical Efficiency		Descriptive Statistics of Scale Efficiency	
Min	0.572	Min	0.700
Max	1	Max	1
Mean	0.860	Mean	0.935
SD	0.16	SD	0.08
No. of Efficient units	8	No. of Efficient units	4
Total no. of units	17	Total no. of units	17

Table 4.20 Efficiency scores of 17 airports on peak hour basis

17 Airports - Peak Hour Traffic 2010-11			
Airport	**Pure Technical Efficiency**	**Airport**	**Scale Efficiency**
Delhi	1	Chennai	1
Chennai	1	Goa	1
Goa	1	Guwahati	1
Coimbatore	1	Pune	1
Guwahati	1	Bangalore	0.999
Mumbai	1	Calicut	0.995
Srinagar	1	Jaipur	0.988
Pune	1	Amritsar	0.988
Kolkata	0.899	Srinagar	0.971
Bangalore	0.832	Trivandrum	0.928
Hyderabad	0.828	Mumbai	0.922
Cochin	0.816	Hyderabad	0.921
Calicut	0.771	Ahmedabad	0.891
Ahmedabad	0.726	Delhi	0.875
Trivandrum	0.598	Coimbatore	0.872
Jaipur	0.577	Cochin	0.848
Amritsar	0.572	Kolkata	0.7

The peers for the airports which have scored less than 100 % are as in table 4.21 below. The result shows that Goa has appeared 8 times as peer, followed by Chennai 7 times. For the Indian airports under evaluation, which have efficiency score less than 100 %, the peers have been highlighted which have highest peer weight compared with other peers.

Table 4.21- Peers for 17 airports on peak hour basis

Airport	Peers
Hyderabad	Delhi, **Chennai**, Goa
Cochin	Delhi, **Goa**
Trivandrum	Chennai, Delhi, Goa
Calicut	Goa, Chennai, Guwahati
Kolkata	**Goa**, Delhi, Chennai
Ahmedabad	Goa, Delhi, Mumbai
Bangalore	**Chennai**, Guwahati, Srinagar, Pune
Jaipur	Goa, Guwahati, Chennai
Amritsar	Pune, Goa, Chennai

4.10 CONCLUDING REMARKS

Efficiency of the airports in three groups has been derived. It is demonstrated that the efficiency scores need not be the same for annual basis and peak hour basis and since efficiency scores are relative it is necessary that the number of airports chosen are large in numbers. Also the stability of the scores is confirmed through the descriptive statistics of the scores. In Chapter 6 the efficiency scores will be analyzed for each airport.

CHAPTER 5

FINANCIAL PERFORMANCE EVALUATION USING SMOP METHODOLOGY

5.1 OVERVIEW

Benchmarking the financial performance of the airports with partial financial factors is quite popular**.** However overall financial performance using the partial factors is essential. Also the aim of the study is to evaluate the financial efficiency not the financial performance. In this Chapter a brief on SMOP methodology is presented with necessity to standardize the data and also to note that the value of the surface area of the polygon depends on the sequence of the performance measures in which it is drawn. Revenue and Cost for an airport is explained and partial financial factors chosen with reasoning and applied to the radar chart and financial efficiency of the airports calculated.

5.2 SURFACE MEASURE OF OVERALL PERFORMANCE METHODOLOGY (SMOP)

5.2.1 RADAR CHART

A radar chart is one where four or more performance indicators are presented in one integrating radial chart which looks like a radar screen or a spider web; hence it is called as radar chart. Connecting these performance indicators attained in each dimension of the radar chart by straight lines produces an angular plane figure, as shown in figure below

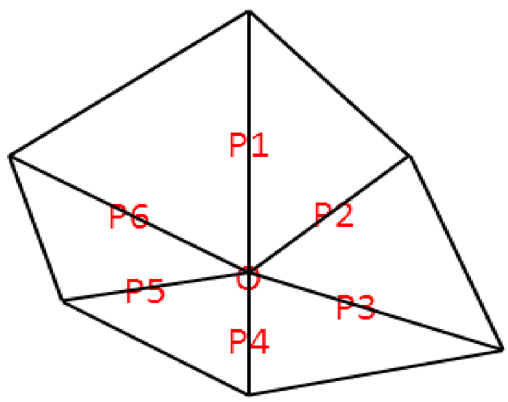

Fig 5.1- Radar Chart

The surface area of this figure can be calculated to give a dimensionless mathematical expression of overall performance achieved in all the measured dimensions. Hence, such a measurement of overall performance is called Surface Measure of Overall Performance (SMOP).

Using radar chart the surface that is formed by the joined lines of each performance indicator generates one single aggregated performance indicators **[27].** Normally, the radar chart is constructed as a polygon for benchmarking purpose with each of the performance measures are proportioned with targeted or standard performance. This process is repeated for all the parameters. The values thus obtained will lie between 0 and 1. These values are used to construct one polygon for each unit under evaluation. It is to note that there is no standard value for the performance indicators of the airports and hence, standardization of data is required.

5.2.2 STANDARDIZATION OF DATA

The performance indicators may not be in the same unit and scale. It is important to depict multiple performance indicators on the same scale and to use the area of the polygon formed by connecting the performance indicators on the radar chart as a composite indicator of overall performance. Different scales of the performance indicators may result in an unequal weighting of the performance dimension of the values. Various methods have been adopted for the standardization of data, benchmarking with average values or maximum values or considering highest as 1 and the lowest as 0. In this paper the highest value of the performance indicator of an airport is taken as 1 and the value of other airports are benchmarked with this. This is repeated for all the performance indicators.

5.2.3 FORMULA FOR CALCULATING THE OVERALL PERFORMANCE

The parameters of each airport are plotted in radar chart as a polygon and the surface area is calculated using trigonometric functions. Formula below is to calculate the overall performance through SMOP of a unit which has n performance indicators P1 to Pn

SMOP = [(P 1*P 2) + (P 2 * P 3) + ----- + (P n * P 1)] * Sin (360/n) 2

5.2.4 SEQUENCE OF THE PERFORMANCE MEASURES

The surface area of the polygon will depend on the sequence of the axis with which it is constructed. Thus various sequences will arrive at different surface area. To overcome this, in this paper all the possible combination of the axes have been worked out and the SMOP value for each of the combination is calculated and average value of all these combinations have been taken as final SMOP value.

5.2.5 SAMPLE SIZE

SMOP methodology has been used for the Major Airports defined in AERA Act. There are twelve major airports as per AERA, out of which Goa and Pune are civil enclaves (AAI operates & maintains only the terminal building &

apron whereas Defence unit operates and maintains the airfield), hence these two airports are not included in the analysis as the revenue sources at civil enclaves are different than at other AAI airports.

5.3 REVENUE AND COST

5.3.1 REVENUE FROM AIRPORT

Airport revenue is from the passengers, airlines and the users of the commercial activities- passengers and others. The discussion here is exclusive of revenues from the Air Traffic Management, Communication & Navigational services and Met services.

In general the services at an airport and hence, revenues are classified into two categories based on services provided viz. Aeronautical and Non-Aeronautical. Aeronautical fee or popularly called as **tariff is regulated** and hence, determined by the Aviation Regulator. Whereas the **non-aeronautical charges** are **market driven** and not regulated.

Aeronautical revenue

Following are the aeronautical service provided [32]

- Navigation, surveillance and supportive communication thereto for air traffic management;
- Landing, housing or parking of an aircraft or any other ground facility offered in connection with aircraft operations at an airport;
- Providing ground safety services at an airport;

For the aeronautical services provided the airport operator charges a fee and these are [21]

- Aircraft landing charges- Charges collected from the aircraft operators for the use of airfield pavements & facilities including lighting
- Passenger Service Charges- Charges collected from the passengers (through the aircraft operators) for the use of passenger terminal building & other facilities.
- Cargo Charges- Charges collected for the use of airports freight processing facilities and areas
- Parking and housing charges- Charges collected from the aircraft operators for the parking of apron at the apron. Charges for the housing of the aircraft at the hangars of the airport is also classified under this head
- Security charges- Charges collected from the passenger (through the aircraft operators) for the security services provided at the airport for the protection of passengers and other persons at the airports, aircrafts and other property.
- Noise related charges- Charges collected from the aircraft operator for noise alienation and prevention measures
- Others (Development Fee)

Revenues from non-aeronautical Services [21]

Any revenues received by an airport in consideration for the various commercial arrangements it makes in relation to the granting of concessions, the rental or leasing of premises and land, and free-zone operations, even though such arrangements may in fact apply to activities which may themselves be considered to be of an aeronautical character (for example, concessions granted to oil companies to supply aviation fuel and the rental of terminal building space or premises to air carriers). Gross revenues earned by shops or services operated by the airport itself.

Airport operator's Revenues from commercial activities are

- **Aviation fuel & oil concessions**- These are the Concession fees including throughput charges payable by oil companies or the operating company for the right to sell or distribute aviation fuel & lubricants at the airport.
- **Restaurant, bars, cafeteria and shops**- If these are operated by the airport operator themselves then the revenue from these services will be to airport account. If operated by a concessionaire then only the Fees and charges payable by the commercial enterprises for the right to operate these services will be to airport account. Aircraft catering is included in these services.
- **Duty Free shops, Car Parking Services**- If these are operated by the airport operator themselves then the revenue from these services will be to airport account. If operated by a concessionaire then only the Fees and charges payable by the commercial enterprises for the right to operate these services will be to airport account.
- **Rentals**- These are the rents collected from the tenants at the airport like airlines, Government authorities and other service providers for their offices. The rent could be for buildings or for the land allotted to them. These will also include the land lease rentals if allotted to the service providers.

- **Others**- These include charges for the services provided by the airport operator like electricity, water, air-conditioning, cleaning, and telephone to the concessionaires.

5.3.2. COST OF SERVICES AT AIRPORTS [21]

The cost/ expenses can be broadly classified as

- Operation and maintenance consisting of costs on personnel, suppliers and service contracts for the services outsourced to third parties.
- Administration and overhead costs, common administrative services for overall management

5.4 PARAMETERS FOR SMOP METHODOLOGY

The following details provide the rationale of the parameters. In the DEA methodology the infrastructure at an airport are considered. In the case of SMOP method the partial financial factors are considered to construct a polygon and the area of the polygon is the financial measure of the airport.

The following partial financial factors are considered

Aeronautical Revenue per Passenger is an important factor for an airport's financial performance. Aeronautical tariff is arrived at with an aim to provide a reasonable rate of return to the airport operator for the capital investment made by them. Since we are measuring the efficiency as performance, less of this is better for the passengers and hence, this ratio has been inversed in the analysis. Airlines also would like to have this ratio less. The aeronautical revenue includes the development fee which is the viability gap funding for the capital invested. Cargo revenue is not included as there is no commonality in treating this as aeronautical revenue in India.

Non- Aeronautical Revenue to Gross Revenue is also an important factor, as a higher value of the ratio is better for the airlines and less pressure on the airport operator so that they need not depend on the Aeronautical Revenue for return on their capital investment. There are three methods for arriving at aeronautical tariff to provide a reasonable return to the airport operator on the capital invested. The first method is to consider only the revenue accruing out of aeronautical services, dual till; the 2nd method is to consider revenues from **both** aeronautical and non-aeronautical services, single till. The first method is preferred by the airport operators whereas the second method is preferred by airlines, as this would result less of aeronautical tariff. The third method is to consider a percentage of non-aeronautical revenue (say 30 %) and add to aeronautical revenue and arrive at the aeronautical tariff, hybrid till. In India hybrid till is specified for Delhi and Mumbai airports in the OMDA and AERA has issued a consultation paper for adopting hybrid till. Airports try to increase the non-aeronautical revenue. Hence, performance measure based on this is relevant.

EBITDA Margin- is the ratio of (Net Revenue- Cost) / Net Revenue. More of this means better operating revenue ratio from the airport. This ratio is commonly used for benchmarking as this is comparable between the business units.

Non- Aero Revenue per Passenger- This will show the yield from the non-aeronautical revenue in terms of revenue from commercial activities at the airport. More of this means, less pressure on aeronautical tariff. Many airports use this ratio for either bench marking self with previous years or peer bench marking to see how other airports' performance is better than its.

Cost per Passenger – Airport operator would like to optimize his operating cost in order to sustain with the available revenue sources. As less of this ratio is a better performance, this ratio has also been inversed in the analysis. Since the aeronautical tariff is determined based on the principle that the airport operator gets a reasonable rate of return on capital investment considering the expenses, the cost incurred on providing services and operation of an airport is an important performance measure.

Gross Revenue per Cost indicates the efficiency of increasing the revenue at the same time reducing the cost

These factors are chosen such that they are not dependent on the business model that is practiced at the airport; otherwise comparison between the airports will be misleading.

5.5 EVALUATION OF FINANCIAL EFFICIENCY

The absolute values of revenue and cost of these airports are in table 5.1 below

Table 5.1 Absolute values of revenue and cost of 10 airports

Airport	Aero Revenue	Non-aero Revenue	Gross Revenue including others	Net Revenue	Cost	EBITDA
Cochin	54.46	127.00	195.46	195.46	67.00	128.00
Mumbai	406.00	477.00	1175.00	720.28	258.00	462.28
Bangalore	331.00	180.80	537.80	516.29	176.00	340.29
Kolkata	82.00	174.00	285.00	285.00	187.00	98.00
Chennai	149.00	263.00	554.00	554.00	235.00	319.00
Ahmedabad	60.52	38.00	98.52	99.00	42.21	56.79
Delhi	465.00	560.00	1250.00	675.00	562.00	113.00
Hyderabad	297.00	220.00	538.00	516.48	198.00	318.48
Calicut	42.00	21.21	69.21	69.00	20.00	49.00
Trivandrum	38.00	20.56	58.56	59.00	45.00	14.00

The partial financial measures based on the absolute revenue and cost are as below in table 5.2

Table 5.2 Partial financial measures based on the absolute revenue and cost

Airport	PAX/Aero Revenue	Non-aero Revenue /PAX	Gross Revenue/ Cost	Non-aero Revenue/ Gross Revenue	PAX/ Cost	EBITDA Margin
Cochin	0.007969	**292.62**	2.2685	**0.6497**	0.6478	0.6564
Mumbai	0.00716	164.08	**4.554**	0.40595	**1.1267**	0.6418
Bangalore	0.00350	155.99	3.0556	0.33618	0.6585	0.6591
Kolkata	**0.01174**	180.68	1.524	0.6105	0.515	0.3438
Chennai	0.00808	218.43	2.357	0.4747	0.5123	0.5758
Ahmedabad	0.006675	94.059	2.334	0.3857	0.9571	0.57363
Delhi	0.006438	187.04	2.224	0.448	0.5327	0.16740
Hyderabad	0.0025589	289.47	2.7171	0.4089	0.3838	0.6166
Calicut	0.00488	103.46	3.4605	0.30645	1.025	**0.7101**
Trivandrum	0.006631	81.59	1.30133	0.35109	0.56	0.2372

In the table 5.2 above the highlighted are the highest values of the partial factors on each performance indicators. The standardized values for the SMOP methodology are obtained by benchmarking against the highest value. The standardized values are as in table 5.3 below

Table 5.3 Standardized values of partial financial measures

Airport	PAX/Aero Revenue	Non-aero Revenue /PAX	Gross Revenue/ Cost	Non-aero Revenue/ Gross	PAX/ Cost	EBITDA Margin
Cochin	0.678	**1**	0.4981	**1**	0.5749	0.92433
Mumbai	0.609	0.5607	**1**	0.62479	**1**	0.9037
Bangalore	0.298	0.53309	0.67095	0.5174	0.5844	0.92821
Kolkata	**1**	0.61746	0.33464	0.9396	0.4570	0.4842
Chennai	0.688	0.7464	0.5176	0.73063	0.4547	0.8108
Ahmedabad	0.568	0.3214	0.51249	0.5936	0.8494	0.8077
Delhi	0.5484	0.6391	0.48837	0.68949	0.4728	0.2357
Hyderabad	0.2178	0.0.9892	0.5966	0.62935	0.3406	0.86832
Calicut	0.4156	0.3535	0.75983	0.471657	0.9097	**1**
Trivandrum	0.5646	0.2788	0.28574	0.54035	0.4970	0.3341

The radar charts are drawn with the performance measures as in table 5.3 for airports comparison. A comparison between two airports Mumbai & Delhi and Chennai & Bangalore is as below in figs 5.2 and Fig 5.3 based on the values of performance measures shown in table 5.3 for these airports.

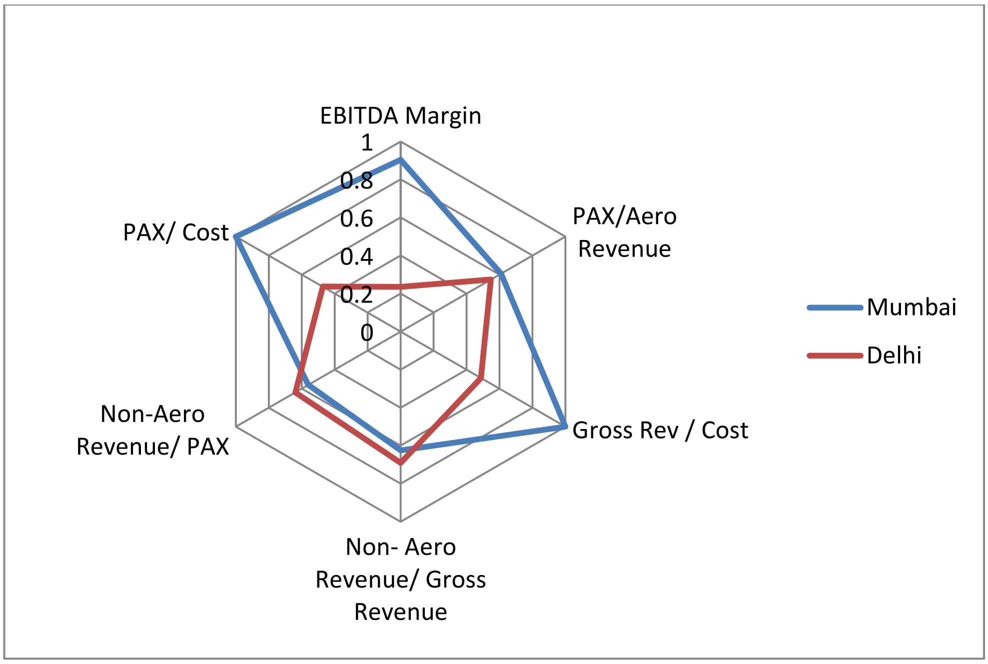

Fig 5.2 Radar chart for Mumbai and Delhi Airports

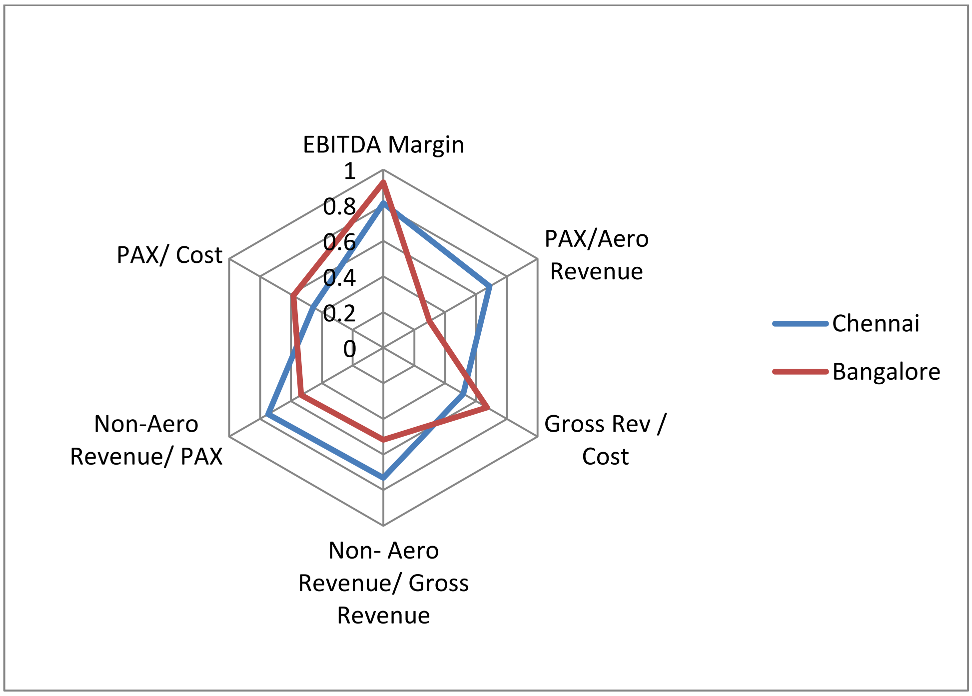

Fig 5.3 Radar chart for Chennai and Bangalore Airports

Similar comparison with radar charts can be obtained for the airports one would like to compare. These radar charts give a visual presentation of the performance measures.

The overall performance is calculated for each airport using the formula

SMOP = [(P 1*P 2) + (P 2 * P 3) + ----- + (P 6 * P 1)] * Sin (60) / 2.

This formula is applied with all the possible combinations of axes. The final overall performance value is the average value of the sum of the values of all the combinations of the axes. The financial efficiency of the airports using SMOP methodology is shown in table 5.4 below

Table 5.4 Financial efficiency scores of 10 airports

Cochin	1.556
Mumbai	1.575
Bangalore	0.882
Kolkata	1.028
Chennai	1.116
Ahmedabad	0.946
Delhi	0.671
Hyderabad	0.919
Calicut	1.070
Trivandrum	0.618

From the efficiency scores it is seen that Mumbai has the highest efficiency score followed by Cochin and Chennai. Trivandrum has the lowest score.

5.6 CONCLUDING REMARKS

In this Chapter the financial efficiency of 10 airports has been calculated using SMOP methodology after standardization of data.

CHAPTER 6

FINDINGS AND CONCLUSION

6.1 BRIEF ON PRODUCTIVE EFFICIENCY USING DEA METHODOLOGY

The findings based on DEA are only for pure technical efficiency. The airport for which the efficiency is less than 100 % shows that the airport has definitely the capacity to handle additional traffic.

The airport for which the efficiency is 100 % is with reference to the group of airports with which it is compared. Hence, the efficiency is not absolute, it is only relative.

The performance analysis based on annual traffic has the component of passengers and cargo handled. Hence, the performance score is on airport basis. Whereas the performance evaluation based on peak hour traffic is only of the passenger terminal building.

The input & output targets are for the pure technical efficiency.

6.2 FINDINGS OF THE PERFORMANCE EVALUATION OF 7 AIRPORTS

In the tables the highlighted parameter indicates slack. If the input has slack means even if the airport achieves the output target values, 100% efficiency will be achieved only when the input is reduced to the target value indicated.

6.2.1 DELHI AIRPORT

6.2.1.1 PRODUCTIVE EFFICIENCY

The performance of Delhi airport on productive efficiency for the year 2010-11 based on DEA methodology when compared with 40 airports, 27 airports and 17 Indian airports, along with the input and output targets are as below for annual basis and peak hour basis are in in table 6.1 and 6.2

Table 6.1 Efficiency scores of Delhi Airport with input and output targets on annual basis

DELHI AIRPORT – ANNUAL BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.911 / 0.883	0.911 / 0.946	1 / 0.776
Scale efficiency / Mean Value				0.515 / 0.743	0.893 / 0.875	0.497 / 0.845
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					As the pure technical efficiency is 100%, the actual and targets are same.
1	Passengers	Million	29.94	34	33.9	
2	ATM	Nos.	255549	280456	280456	
3	Cargo	Tons	600045	658258	658528	
4	Airlines	Nos.	59	65	65	
5	Destinations	Nos.	112	122	123	
	Input					
1	PTB area	Sq.m	549367	515207	515207	
2	Cargo Area	Sq.m	70000	70000	70000	

The airport's pure technical efficiency is 100% when compared with 17 airports whereas 91.1 % when compared in other two groups. The scale efficiency is less than the mean value in all the three groups of comparison. The area of the passenger terminal building shows slack when the PTE is less than 100 %. The airports performance for the peak hour passenger traffic is as below in table 6.2 below

Table 6.2 Efficiency scores of Delhi Airport with input and output targets on peak hour basis

DELHI AIRPORT – PEAK HOUR BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency Mean value				0.709 0.893	0.856 0.953	1 0.86
Scale efficiency Mean Value				0.921 0.906	0.931 0.912	0.875 0.935
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					As the pure technical efficiency is 100%, the actual and targets are same.
1	Peak PAX	Nos.	10500	12263	12263	
2	Peak ATM	Nos.	60	70	70	
	Input					
1	Check in counters	Nos.	250	250	250	
2	Apron bays	Nos.	128	128	128	
3	PTB Area	Sq.m	549367	450189	450189	

Similar to annual basis the performance of pure technical efficiency of the airport is less than 100 % when compared with 40 airports and 27 airports and 100% when compared with 17 airports. However, the scale efficiency is less than 1 when pure technical efficiency is 1, shows that the **airport is not operating in the Most Productive Scale Size (MPSS)**. The area of the terminal building also shows a slack. The efficiency less than 100% show that the terminal has adequate capacity to handle additional traffic without any requirement of increase in infrastructure.

The airport’s productive efficiency is 100 %, both on annual basis and peak hour basis, when compared in group 3 with 17 airports as the peers for the airports under group 1 and 2 (tables 4.6, 4.9, 4.15 and 4.18) are all overseas airports which does not appear in comparison for group 3 since in this group only Indian airports are compared. This shows the importance and sensitivity of the scores with the airports being compared, since when compared with overseas airports the efficiency is not only less than 100%, it shows that the area of the terminal building has slack. **The peer for Delhi airport is Sydney airport** in all the cases when the airport efficiency is less than 100 %. Since the airport efficiency on annual basis is more than 90%, it can be classified as marginally in-efficient and on peak hour basis the airport can be classified as distinctively in-efficient.

6.2.1.2 FINANCIAL EFFICIENCY

The airport has scored 0.671 against the highest value of 1.575 of Mumbai airport. It has the lowest normalized value of 0.2357 in the performance indicator of EBITDA. One of the reasons EBITDA margin is less due to share of revenue with AAI @ 45.99% of gross revenue as per OMDA. Its higher cost is also pulling its performance down. The higher cost could be due to the adequate infrastructure created for future traffic.

6.2.1.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

The ASQ score of the airport for the year 2010-11 is 4.49 which is next to Hyderabad with 4.51 as the highest score by an Indian airport and ahead of 4.39 of Mumbai.

6.2.2 HYDERABAD AIRPORT

6.2.2.1 PRODUCTIVE EFFICIENCY

The performance of Hyderabad airport on productive efficiency for the year 2010-11 based on DEA methodology when compared with 40 airports, 27 airports and 17 Indian airports, along with the input and output targets are as below for annual basis and peak hour basis are in in table 6.3 and 6.4

Table 6.3 Efficiency scores of Hyderabad Airport with input and output targets on annual basis.

HYDERABAD AIRPORT – ANNUAL BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.587 / 0.883	0.622 / 0.946	0.696 / 0.776
Scale efficiency / Mean Value				0.520 / 0.743	0.989 / 0.875	0.493 / 0.845
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					
1	Passengers	Million	7.6	12.94	12.2	14.5
2	ATM	Nos.	82658	140769	132876	121411
3	Cargo	Tons	78487	202564	238762	291220
4	Airlines	Nos.	18	30	29	28
5	Destinations	Nos.	41	69	66	59
	Input					
1	PTB area	Sq.m	105300	105300	105300	105300
2	Cargo Area	Sq.m	28172	28172	28172	28172

The airport is designed for 12 million passengers per annum and the performance of the airport on annual basis shows that the efficiency is less than 100 % when compared in all the three groups. In addition the evaluation shows slack in cargo output. When analyzed for peak hour traffic the airport's performance as in table 6.4 below shows that there is adequate capacity available.

Table 6.4 Efficiency scores of Hyderabad Airport with input and output targets on peak hour basis.

HYDERABAD AIRPORT – PEAK HOUR BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.709 / 0.893	0.900 / 0.953	0.828 / 0.860
Scale efficiency / Mean Value				0.991 / 0.906	0.877 / 0.912	0.921 / 0.935
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					
1	Peak PAX.	Nos.	2391	3373	2655	3219
2	Peak ATM	Nos.	20	28	22	24
	Input					
1	Check in counters	Nos.	62	62	62	62
2	Apron bays	Nos.	45	45	45	45
3	PTB Area	Sq.m	105300	103515	83164	72531

In all the three groups of comparison the performance is less than 100 % on pure technical efficiency and scale efficiency. **Scale efficiency less than 1 show that the airport is not operating in MPSS**. Also there is a slack in the area of the terminal building. The peer for Hyderabad airport is Ottawa airport when compared with 40 airports on annual basis as well as on peak hour basis and Chennai when compared with 27 airports on annual basis and with 17 airports on peak hour basis, whereas when compared with 27 airports on peak hour basis the peer airport is Bangalore and when compared with 17 airports on annual basis Ahmedabad is the peer. Since the efficiency of the airport in all the cases is less than 90% it falls in the classification of distinctively in-efficient.

6.2.2.2 FINANCIAL EFFICIENCY

The airport's score on SMOP is 0.919 and stands at 7th position out of 10 airports analyzed. Cost is pulling its performance down; the higher cost is due to the actual traffic handled is far less than the capacity. Its number of passengers handled per aeronautical revenue is also low meaning the aeronautical charges are high.

6.2.2.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

Hyderabad airport had scored 4.51 and achieved No. 1 ranking in the world in the airport group that handled between 5 & 15 million passengers per annum.

6.2.3 COCHIN AIRPORT

6.2.3.1 PRODUCTIVE EFFICIENCY

The performance of Cochin airport on productive efficiency for the year 2010-11 based on DEA methodology when compared with 40 airports and 17 Indian airports, along with the input and output targets are as below for annual basis and peak hour basis are in in table 6.5 and 6.6. The airport has handled less than 5 million passengers per annum and hence they have not been evaluated for the group of 27 airports. The airport has adequate capacity as the performance is less than 100 % and as the cargo handled is very less for the cargo area available the efficiency score is very less. The airport **is not operating in** the Most Productive Scale Size **(MPSS)** as the scale efficiency is less than 1 in all the three groups and on annual as well as peak hour basis.

Table 6.5 Efficiency scores of Cochin Airport with input and output targets on annual basis

COCHIN AIRPORT – ANNUAL BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.696 / 0.883		0.696 / 0.776
Scale efficiency / Mean Value				0.487 / 0.743		0.487 / 0.845
Input/ Output Parameters			Actual	Target (40 Airports)		Target (17 Airports)
S.No.	**Output**					
1	Passengers	Million	4.34	14		14
2	ATM	Nos.	40419	122818		122818
3	Cargo	Tons	40808	302632		302632
4	Airlines	Nos.	18	29		29
5	Destinations	Nos.	41	59		59
	Input					
1	PTB area	Sq.m	53700	53700		53700
2	Cargo Area	Sq.m	30500	29971		29971

Table 6.6 Efficiency scores of Cochin Airport with input and output targets on peak hour basis

COCHIN AIRPORT – PEAK HOUR BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.730 / 0.893		0.816 / 0.860
Scale efficiency / Mean Value				0.947 / 0.906		0.848 / 0.935
Input/ Output Parameters			Actual	Target (40 Airports)		Target (17 Airports)
S.No.	**Output**					
1	Peak PAX	Nos.	1600	2192		1961
2	Peak ATM	Nos.	10	14		13
	Input					
1	Check in counters	Nos.	57	50		48
2	Apron bays	Nos.	17	17		17
3	PTB Area	Sq.m	53700	52740		44159

The airport's performance for the peak hour basis shows that it has adequate capacity to increase the peak hour traffic. The scores for the peak hour traffic are more than annual basis. The performance analysis also shows slack in number of check-in counters and passenger terminal building area. The peer for Cochin airport is Guwahati and Goa for annual basis and peak hour basis respectively. Based on the efficiency scores the airport falls in the classification of distinctively in-efficient.

6.2.3.2 FINANCIAL EFFICIENCY

The financial efficiency score of SMOP methodology is 1.556 next to the highest score of 1.575 by Mumbai. The airport's non-aeronautical revenue per passenger and Non-aeronautical revenue per Gross revenue is the highest among the 10 airports compared. Its gross revenue per cost is low compared to Mumbai.

6.2.3.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

The airport did not participate in the ASQ survey and hence not assessed.

6.2.4 CHENNAI AIRPORT

6.2.4.1 PRODUCTIVE EFFICIENCY

With reference to tables 4.4, 4.7, 4.10, 4.13, 4.16 & 4.19 it could be seen that the performance of the airport on annual basis is 100 % on all the three groups of airports and both on annual basis and peak hour basis. The airport is constrained with the present infrastructure and additional infrastructures are being created now. Peer count of Chennai airport is many times in all the analysis except when compared on annual basis with 17 airports and 40 airports. Hence, the airport may be classified as distinctively efficient on peak hour basis and marginally efficient on annual basis. **The airport is operating**

in Most Productive Scale Size (MPSS) as the scale efficiency is 1 in all the groups and both on annual basis and peak hour basis

6.2.4.2 FINANCIAL EFFICIENCY

The airport's overall performance of financial efficiency through SMOP methodology is 1.116, no. 3 position among the 10 airports compared and its higher cost is pulling down its performance.

6.2.4.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

The ASQ score of the airport for the year 2010-11 is 3.39 (second position from the bottom when compared with 154 airports participated in the survey). One of the reasons in addition to not a good quality service delivery is the infrastructure constraint would have resulted in the poor scoring by the passengers in the ASQ survey. It would be interesting to see the ASQ score when the infrastructures are put into operation.

6.2.5 MUMBAI AIRPORT

6.2.5.1 PRODUCTIVE EFFICIENCY

For the year 2010-11, on annual basis as well as on peak hour traffic basis, the productive efficiency is 100% on pure technical efficiency score and scale efficiency, that too in all the three groups of comparison that is among 40 airports, 27 airports and 17 Indian airports. **The airport is operating in Most Productive Scale Size (MPSS)** as the scale efficiency is 1 in all the groups on annual basis and when compared with 27 airports on peak hour basis.

The airport with a smaller terminal building is handling a very high traffic. The airport is working in a constrained environment and a new terminal building is being constructed which is nearly 4 times of the existing terminal building.

This may be one of the reasons its financial efficiency is also high. It would be interesting to see the efficiency of the airport both on productivity and on financial when the expansion works are completed and put into operation.

Peer count of Mumbai airport is many times in all the three groups when evaluated on annual basis and only once when evaluated on peak hour basis. Hence, the airport can be classified as distinctively efficient on annual basis and marginally efficient on peak hour basis.

6.2.5.2 FINANCIAL EFFICIENCY

On financial efficiency, the airport has scored 1.575 **the highest** when compared among the 10 airports evaluated. Its partial financial factor on PAX/ cost is the highest and also its gross revenue per cost is the highest among the 10 airports evaluated. Its non-aeronautical revenue per cost is not significant.

6.2.5.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

The ASQ score of the airport in the year is 4.39, No.3 ranking among Indian Airports. However, in a constrained infrastructure the airport has scored a very high ASQ rating.

6.2.6 BANGALORE AIRPORT

6.2.6.1 PRODUCTIVE EFFICIENCY

The performance of Bangalore airport on productive efficiency for the year 2010-11 based on DEA methodology when compared with 40 airports, 27 airports and 17 Indian airports, along with the input and output targets are as below for annual basis and peak hour basis are in in table 6.7 and 6.8

Table 6.7 Efficiency scores of Bangalore Airport with input and output targets on annual basis

BANGALORE AIRPORT – ANNUAL BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency				0.776	0.853	0.776
Mean value				0.883	0.946	0.776
Scale efficiency				0.804	0.970	0.804
Mean Value				0.743	0.875	0.845
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					
1	Passengers	Million	11.59	18.99	16.1	18.99
2	ATM	Nos.	111483	168670	142471	158670
3	Cargo	Tons	222778	414943	456461	413943
4	Airlines	Nos.	31	40	36	40
5	Destinations	Nos.	56	72	71	72
	Input					
1	PTB area	Sq.m	73627	73627	73627	73627
2	Cargo Area	Sq.m	57913	41089	40872	57913

The efficiency score when compared in all the three groups are less than 100% mainly due to its poor performance of cargo handled. The airport shows slack in all the three outputs and slack in cargo terminal building area. The scores are also less than the mean scores of the group.

Table 6.8 Efficiency scores of Bangalore Airport with input and output targets on peak hour basis

BANGALORE AIRPORT – PEAK HOUR BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency				0.803	1	0.832
Mean value				0.893	0.953	0.860
Scale efficiency				0.995	0.832	0.999
Mean Value				0.906	0.912	0.935
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**				As the pure technical efficiency is 100%, the actual and targets are same.	
1	Peak PAX	Nos.	2495	3106		3000
2	Peak ATM	Nos.	20	26		24
	Input					
1	Check in counters	Nos.	53	53		53
2	Apron bays	Nos.	46	46		46
3	PTB Area	Sq.m	73627	73627		54916

The performance of the airport on peak hour basis is 100 % when compared with 27 airports that handled more than 5 million passengers per annum. Otherwise the airport's performance is less than 100 % on other groups. The reason for the airport's 100 % efficiency in this group is Ottawa airport which was its peer when compared with 40 airports do not appear in the group as this group is for airports that handled more than 5 million passengers per annum. When the efficiency is 100 % it appears as peer only once which shows it is marginally efficient when compared in that group, otherwise the efficiency scores of the airport is distinctively in-efficient. It also shows a slack in the size of the passenger terminal building when compared with 17 Indian airports. The airport **is not operating in** the Most Productive Scale Size **(MPSS)** as the scale efficiency is less than 1 in all the three groups and on annual as well as peak hour basis. Bangalore airport's peer airports when its efficiency is less than 100 % are not the same in all the three groups.

The terminal building practically looks congested during peak hours may be due to more areas allotted to commercial activities like shops, food & beverages. The terminal is being expanded now.

6.2.6.2 FINANCIAL EFFICIENCY

The overall financial efficiency is 0.882. Its passenger per aeronautical revenue is low due to the development fee being levied, its EBITDA margin is very high and its passenger per cost is less.

6.2.6.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

The ASQ score of the airport is 4.12 which is not considered very high for a new airport commissioned in the year 2008 along with Hyderabad airport, this is partly due to congestion seen at the terminal during peak hours for the reason mentioned under productive efficiency.

6.2.7 KOLKATA AIRPORT

6.2.7.1 PRODUCTIVE EFFICIENCY

The performance of Kolkata airport on productive efficiency for the year 2010-11 based on DEA methodology when compared with 40 airports, 27 airports and 17 Indian airports, along with the input and output targets are as below for annual basis and peak hour basis are in in table 6.9 and 6.10

Table 6.9 Efficiency scores of Kolkata Airport with input and output targets on annual basis

KOLKATA AIRPORT – ANNUAL BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.803 / 0.883	0.836 / 0.946	0.806 / 0.776
Scale efficiency / Mean Value				0.727 / 0.743	0.990 / 0.875	0.725 / 0.845
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**					
1	Passengers	Million	9.6	14.86	13.19	17.01
2	ATM	Nos.	94375	133605	119715	145536
3	Cargo	Tons	129957	305324	407904	373073
4	Airlines	Nos.	24	29	33	34
5	Destinations	Nos.	54	67	65	67
	Input					
1	PTB area	Sq.m	65365	65365	65365	65365
2	Cargo Area	Sq.m	36927	36927	36927	36927

The performance score is less than 100 % on all the three groups which is mainly due to less cargo handled with the cargo area created.

Table 6.10 Efficiency scores of Kolkata Airport with input and output targets on peak hour basis

KOLKATA AIRPORT – PEAK HOUR BASIS – 2010 -11						
Compared with				40 Airports	27 Airports	17 Airports
Pure technical efficiency / Mean value				0.758 / 0.893	1 / 0.953	0.899 / 0.860
Scale efficiency / Mean Value				0.827 / 0.906	0.841 / 0.912	0.700 / 0.935
Input/ Output Parameters			Actual	Target (40 Airports)	Target (27 Airports)	Target (17 Airports)
S.No.	**Output**				As the pure technical efficiency is 100%, the actual and targets are same.	
1	Peak PAX	Nos.	2340	3097		2796
2	Peak ATM	Nos.	18	24		20
	Input					
1	Check in counters	Nos.	94	94		58
2	Apron bays	Nos.	35	35		35
3	PTB Area	Sq.m	65365	65365		65365

The performance of the airport on peak hour basis is less than 100 % on two groups and 100 % when compared with airports handled more than 5 million passengers per annum for the similar reason that of Bangalore airport. The airport **is not operating in** the Most Productive Scale Size **(MPSS)** as the scale efficiency is less than 1 in all the three groups and on annual as well as peak hour basis. The input targets show slack in check-in counters when compared with 17 Indian airports. When the efficiency is 100 % it appears as peer only once which shows it is marginally efficient when compared in that group, otherwise the efficiency scores of the airport falls under distinctively efficient unit.

6.2.7.2 FINANCIAL EFFICIENCY

The airport's overall financial performance is 1.028. Its passenger per aeronautical revenue is the highest among the airports compared, where as its gross revenue per cost and passenger per cost is pulling its overall performance.

6.2.7.3 PERFORMANCE EVALUATION ON EFFECTIVENESS

ASQ score of the airport for the year 2010-11 is 3.23, which is the lowest among the Indian airports and ranked at 154 in the world.

6.3 SUMMARY OF THE PERFORMANCE OF 7 INDIAN AIRPORTS

Summary of the performance of the 7 Indian airports for the year 2010-11 on three aspects- Effectiveness (ASQ rating), Pure Technical Efficiency and financial efficiency is as below in table 6.11

Table 6.11 Summary of performance of 7 Indian airports on efficiency and effectiveness

Airport	Productive Efficiency		Financial Efficiency	ASQ score
	Annual	Peak Hour		
Mumbai	1	1	1.575	4.39
Delhi	0.916	0.709	0.671	4.49
Bangalore	0.776	0.803	0.882	4.12
Hyderabad	0.587	0.709	0.919	4.51
Cochin	0.696	0.730	1.556	NP
Kolkata	0.803	0.758	1.028	3.23
Chennai	1	1	1.116	3.39

The first 5 airports in the table are the airports under PPP model and the other two are AAI airports. ASQ score of the PPP airports are very high.

In order to check the stability of the efficiency scores the productive efficiency of the airports were evaluated for the year 2011-12, with traffic for the year and with additional infrastructure of Chennai & Kolkata airports which were to be completed in the year 2011 (but delayed for operations). When the efficiency scores of year 2010-11 were compared with that of year 2011-122 all the airports show either increase over the year 2010-11 or the same as that of year 2010-11 except Chennai & Kolkata which show decrease. The table 6.12 below shows the efficiency scores of group 1 with 40 airports along with ASQ scores of both the years. The master data for 2011-12 are in **Appendix 11 & 12**

Table 6.12 Efficiency & ASQ Score comparison of year 2010-11 & 2011-12

Airport	PTE on annual basis		PTE on peak hour basis		ASQ Score	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Delhi	0.911	0.989	0.709	0.856	4.49	4.60
Hyderabad	0.587	0.609	0.709	0.705	4.51	4.81
Bangalore	0.776	0.776	0.803	0.808	4.12	4.23
Cochin	0.696	0.696	0.730	0.730	[redacted]	[redacted]
Chennai	1	0.931	1	0.586	3.39	3.07
Kolkata	0.803	0.564	0.758	0.397	3.23	2.87
Mumbai	1	1	1	1	4.39	4.65

The efficiency decrease for Chennai and Kolkata is due to the additional infrastructure in the year. The ASQ scores of the PPP airports have shown increase and of AAI airports reduced.

6.4 CONCLUSION

In this research the objectives as stated in Chapter 1 have been met. Most importantly the performance of major Indian airports, a mix of AAI and PPP airports has been evaluated through the measure of efficiency and effectiveness.

For the same airport, the efficiency scores obtained on annual basis and peak hour basis could be different and it is worthwhile to evaluate the performance on both aspects. The targets for the annual basis for some airports are impracticable; however the efficiency scores are realistic. However, the targets projected for the peak hour basis is realistic.

A productive efficiency of 100 % both on annual basis and peak hour basis means the airport infrastructure may be reaching to its capacity; this is particularly true when compared with large number of airports. It would be worthwhile in that case to examine whether the airport is already improving its infrastructure or has plans to improve. Alternatively may check whether improvement in the process or use of advanced technology can be implemented without additional infrastructure. When the peak hour basis efficiency shows 100 % or near to that it is worthwhile to examine the possibility of increasing the traffic on non-peak hours through slot allocation.

All the 7 airports that are evaluated have shown increase in productive efficiency when compared in the group 2 with 27 airports that have handled more than 5 million passengers per annum. Normally the smaller airports are optimum in size with reference to the infrastructure and hence, when not included in the comparison the efficiency of other airports show increase in productive efficiency.

In this study only **Mumbai airport's** performance on productive efficiency and financial efficiency are the highest, with 2^{nd} highest ASQ score among the Indian airports.

Hyderabad airport has the highest ASQ score but has lesser productive efficiency and financial efficiency.

Cochin airport which has not participated in ASQ rating and whose productive efficiency is less than 100% has scored 2nd position in terms of its financial efficiency.

Delhi airport analysis show slack in terminal building area under two groups meaning even when it reaches the targets of passenger & ATM numbers, 100% efficiency will be achieved only when the terminal building size is reduced. As the size of the terminal building cannot be reduced, the output will have to increase beyond the target values to achieve 100 % productive efficiency.

Surprisingly **Kolkata airport's** efficiency score is less than 100 % on annul as well as peak hour basis whereas a new terminal building has been recently inaugurated which is nearly 3 times of the size that of year 2010.

There is no correlation between the PPP airports and AAI airports either on productive efficiency or financial efficiency. However, it is seen that all the PPP airports, except Cochin, have scored much higher ASQ scores than AAI airports. Sensitivity analysis with three groups of airports shows the importance and necessity to include more airports for analysis and evaluate the efficiency than with few airports.

6.5 LIMITATIONS AND FUTURE RESEARCH ON THE SUBJECT

Limitations

- Availability of data on financial breakdowns of the airport
- Technical Efficiency scores are not absolute and the units identified as most efficient could improve its efficiency further.

Future Research

- Benchmarking the financial factors as a periodical analysis using SMOP could be a future work to analyze the performance before and after privatization of Indian airports.
- Relation between the three aspects viz. operational, productive and financial measures could be analyzed with priori weights and a composite efficiency formulation
- Analysis of Scale efficiencies

APPENDIX 1
OBJECTIVE SERVICE QUALITY REQUIREMENTS

Performance Area	Performance Measure	Target
Transfer Process	Minimum connect times	Domestic/International: 60 minutes International/ International: 45 minutes
Terminal Services	Handling of complaints	100% of complaints responded to within 2 working days
	Response to phone calls	5% of calls answered within 20 seconds
	Availability of Flight Information	98% available
	Automated services	98% available
	Lifts, escalators	98% available
	Repair completion time	95% of high priority complaints within 4 hours 95% of others within 24 hours
	Baggage trolleys	100% availability. Cleanliness Achieve a satisfactory cleanliness rating for 95% of all inspections
	Availability of wheel chairs	100% of time within 5 minutes
Check in	Maximum queuing time	5 minutes for business class 20 minutes for economy
Security Check	Waiting time in Queue	95% of passengers wait less than 10 minutes
CIQ	Checking time in queue	95% of passengers wait less than 20 minutes 95% of passengers wait less than 10 minutes
Baggage Delivery	Time for bag delivery from aircraft arrival	Domestic- First bag 10 minutes, last bag 30 minutes from on blocks time International-First bag 15 minutes, last bag 40 minutes from on blocks time.
Passenger arrival process (International)	Time taken from aircraft arrival to Kerbside	95% of passengers take less than 45 minutes

APPENDIX 1 Continued OBJECTIVE SERVICE QUALITY REQUIREMENTS		
Passenger boarding bridges	% passengers served by boarding bridges	International - 90 % of annual passengers Domestic - 90 % of annual passengers Travelling on A/C B737/A320 or larger unless not required by Airlines.
Runway system	Delays to arriving/departing Aircraft	Average annual delay per aircraft: 4 minutes or better based on provision of International Standard ATC procedures and equipment as per CNS/ATM agreement.
Car parking	Average time taken to find parking space	95% of drivers take less than 5 minutes
	Average time to depart airport from parking space	95% of drivers take less than 5 minutes
Taxis	Maximum waiting time	95% of passengers wait less than 5 minutes 95% of passengers wait less than 3 minutes
Gate Lounges	Seating availability	Seats for 80% of gate lounge population
Cargo Services	Average dwell time	For imports, maximum processing time of 24 hours For exports, maximum processing time of 24 hours

APPENDIX 2

SUBJECTIVE QUALITY PARAMETERS

ASQ Survey

The parameters evaluated during the passenger survey are:

Access • Ground transportation to/from airport • Availability of parking facilities • Value for money of parking facilities • Availability of baggage carts/trolleys	**Check-in** • Waiting time in check-in queue/line • Efficiency of check-in staff • Courtesy, helpfulness of check-in staff
Passport and ID control • Waiting time at passport/personal ID inspection • Courtesy and helpfulness of inspection staff	**Security** • Courtesy and helpfulness of security staff • Thoroughness of security inspection • Waiting time at security inspection • Feeling of being safe and secure
Finding your way • Ease of finding your way through the airport • Flight information screens • Walking distance inside the terminal • Ease of making connections with other flights	**Airport Environment** • Cleanliness of airport terminal • Ambience of the airport
Airport facilities • Courtesy, helpfulness of airport staff • Restaurant/eating facilities • Value for money of restaurant/eating facilities • Availability of bank/ATM facilities/money changers • Shopping facilities • Value for money for shopping facilities • Internet access/Wi-Fi • Business/Executive lounges • Availability of wash rooms/toilets • Cleanliness of wash rooms/toilets • Comfort of waiting /gate areas	**Arrivals** • Passport/Personal ID inspection • Speed of baggage delivery Service • Customs inspection

APPENDIX 3

MASTER DATA - ANNUAL FOR THE YEAR 2010-11								
Airport	PAX in Million	Annual ATM	Cargo (Ton)	No. of Airlines	No. of Destinations	Area of Pax terminal	Area of Cargo Terminal	ASQ Score
Hyderabad	7.6	82658	78487	18	41	105300	28172	4.51
Delhi	29.94	255549	600045	59	112	549367	70000	4.49
Changi	42	263600	1820000	100	210	1046220	125000	4.83
Cochin	4.34	40419	40808	19	41	53700	30500	NP
Chennai	12.04	110778	388833	32	62	62120	32866	3.39
Goa	3.08	24018	6782	26	28	16851	1000	NP
Bangkok	42.7	265896	1343533	97	177	563000	660572	4.19
Trivandrum	2.52	24869	39335	17	23	45863	25000	NP
Calicut	2.05	16690	22246	13	18	24000	5950	NP
Coimbatore	1.243	14276	7027	7	11	11430	1000	NP
Kolkata	9.63	94375	129957	24	54	65365	36927	3.23
Guwahati	1.934	26941	8520	13	26	8655	1000	NP
Ahmedabad	4.04	34686	28040	12	29	70423	1000	NP
Incheon	33	210000	2700000	71	176	670640	166911	4.96
Dubai	47.18	326317	2270000	150	220	1444474	175190	4.37
Bangalore	11.59	111483	222778	31	56	73627	57913	4.12
Mumbai	29.07	242651	670233	50	100	110000	66180	4.39
Beijing	73.94	517585	1551471	88	208	1046000	398586	4.67
Jaipur	1.655	14989	8575	8	20	26709	1000	NP
Kuala Lumpur	34.08	244179	694296	55	122	514694	75000	4.48
Munich	34.7	389939	286820	100	242	473750	115000	3.96
Srinagar	1.039	9018	2016	3	6	12000	1000	NP
Amritsar	0.765	9071	5995	10	4	40000	1000	NP
Pune	2.8	21764	27828	9	17	19500	1000	NP
Hongkong	51.5	316000	4200000	100	160	710000	442000	4.78
Frankfurt	53	464432	2160000	107	275	745000	485000	3.58
SGI (Istanbul)	11.12	95097	50000	35	78	210000	11250	NP
Sao Paulo (Brazil)	26.8	264738	433500	40	153	184000	110000	NP
Male'	2.4	20300	45000	15	11	12470	4650	NP
Sydney	35.6	307866	415000	45	99	354000	53850	3.97
Indianapolis	7.526	197202	942279	9	34	110000	176579	4.46
Ottawa	4.473	170946	22000	14	49	65000	18500	4.44
Austin Bergstrom	9.08	188140	67443	10	39	61000	22690	4.43
Vancouver Intl	16.778	254914	228414	48	108	135138	96156	4.38
Narita Intl	32.52	191426	2068000	55	92	813300	295800	4.25
Baiyun China	40.975	329214	1144458	60	110	320000	110000	4.4
Pu Dong Airport	40.58	332100	3200000	87	194	820000	460000	4.57
Taiwan Taoyuan	25.11	156036	1767000	50	75	487500	176700	4.33
Stansted	18.56	130887	230088	14	100	144000	41000	3.77
Manchester	17.7	160570	116655	95	180	340000	60000	3.91
NP- Not participated								

APPENDIX 4

MASTER DATA -PEAK HOUR TRAFFIC FOR THE YEAR 2010-11						
Airport	**Peak Pax**	**Peak ATM**	**Check-in counters**	**Apron Bays**	**Area of Pax terminal**	**ASQ Score**
Hyderabad	2391	20	62	45	105300	**4.51**
Delhi	10500	60	250	128	549367	**4.49**
Changi	12428	60	463	137	1046220	**4.83**
Cochin	1600	10	57	17	53700	**NP**
Chennai	3375	27	59	52	62120	**3.39**
Goa	1500	10	37	11	16851	**NP**
Bangkok	10680	50	360	140	563000	**4.19**
Trivandrum	1200	8	48	19	45863	**NP**
Calicut	1260	7	35	27	24000	**NP**
Coimbatore	720	6	24	8	11430	**NP**
Kolkata	2340	18	94	35	65365	**3.23**
Guwahati	600	6	14	9	8655	**NP**
Ahmedabad	1800	10	62	24	70423	**NP**
Incheon	13279	65	492	148	670640	**4.96**
Dubai	12500	52	381	167	1444474	**4.37**
Bangalore	2495	20	53	46	73627	**4.12**
Mumbai	6230	40	135	84	110000	**4.39**
Beijing	18571	100	452	328	1046000	**4.67**
Jaipur	900	6	30	24	26709	**NP**
Kuala Lampur	9979	55	312	135	514694	**4.48**
Munich	10320	86	270	199	473750	**3.96**
Srinagar	720	6	15	13	12000	**NP**
Amritsar	750	5	30	11	40000	**NP**
Pune	1200	8	27	10	19500	**NP**
Hong Kong	13348	63	377	121	710000	**4.78**
Frankfurt	15938	102	420	189	745000	**3.58**
SGI Istanbul	4256	28	96	42	210000	**NP**
Brazil	6580	50	228	68	184000	**NP**
Male'	851	6	26	10	12470	**NP**
Sydney	11274	75	266	98	354000	**3.97**
Indianapolis	3000	30	96	40	110000	**4.46**
Ottawa	2500	25	40	42	65000	**4.44**
Austin Bergstrom	2400	30	62	68	61000	**4.43**
Vancouver Intl	6000	50	200	91	135138	**4.38**
Narita Intl	13251	60	280	143	813300	**4.25**
Baiyun China	13940	80	246	173	320000	**4.4**
Pu Dong Airport	14296	90	204	218	820000	**4.57**
Taiwan Taoyuan	9655	50	182	81	487500	**4.33**
Stansted	4760	34	127	64	144000	**3.77**
Manchester	6706	60	220	94	340000	**3.91**
NP- Not participated						

APPENDIX 5

Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file = eg5-dta.txt

Output orientated DEA

Scale assumption: VRS

Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm	crste	vrste	scale	
1	0.306	0.587	0.520	drs
2	0.470	0.911	0.515	drs
3	0.749	1.000	0.749	drs
4	0.339	0.696	0.487	drs
5	1.000	1.000	1.000	-
6	1.000	1.000	1.000	-
7	0.373	0.996	0.374	drs
8	0.297	0.508	0.585	drs
9	0.405	0.533	0.760	drs
10	0.568	0.568	1.000	-
11	0.584	0.803	0.727	drs
12	1.000	1.000	1.000	-
13	1.000	1.000	1.000	-
14	1.000	1.000	1.000	-
15	0.669	1.000	0.669	drs
16	0.624	0.776	0.804	drs
17	1.000	1.000	1.000	-
18	0.341	1.000	0.341	drs
19	0.721	0.721	1.000	-
20	0.532	0.921	0.578	drs
21	0.313	1.000	0.313	drs
22	0.433	0.433	1.000	-
23	0.458	0.458	1.000	-
24	1.000	1.000	1.000	-
25	0.916	1.000	0.916	drs
26	0.445	1.000	0.445	drs
27	0.345	1.000	0.345	drs
28	0.579	1.000	0.579	drs
29	1.000	1.000	1.000	-
30	0.562	1.000	0.562	drs
31	1.000	1.000	1.000	-

32	0.845	1.000	0.845	drs
33	0.998	1.000	0.998	drs
34	0.664	1.000	0.664	drs
35	0.515	0.684	0.753	drs
36	0.802	1.000	0.802	drs
37	0.617	0.944	0.654	drs
38	0.735	0.783	0.938	drs
39	0.558	1.000	0.558	drs
40	0.228	1.000	0.228	drs
mean	0.650	0.883	0.743	

Note: crste = technical efficiency from CRS DEA
vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm	output: 1	2	3	4	5
1	0.000	0.000	68897.966	0.000	0.000
2	1.057	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000
4	7.761	64761.634	244017.668	2.155	0.000
5	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000
7	0.000	134672.002	0.000	0.000	58.219
8	6.213	43143.019	135963.889	0.000	5.135
9	0.765	9517.664	10694.896	0.000	0.000
10	0.000	548.604	0.000	0.721	4.918
11	2.881	16135.315	143564.110	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000
16	4.059	15021.790	127887.855	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000
19	0.721	6286.464	0.000	8.687	0.000
20	0.000	35891.602	0.000	1.323	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	4902.387	3150.569	11.371	12.947
23	1.694	7372.456	0.000	0.000	19.560
24	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000

27	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	0.000	0.000
33	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000
35	0.000	37582.996	0.000	22.860	30.819
36	0.000	0.000	0.000	0.000	0.000
37	9.090	22901.997	0.000	10.576	0.000
38	0.000	17441.598	0.000	2.355	46.310
39	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000
mean	0.856	10404.488	18354.424	1.501	4.448

SUMMARY OF INPUT SLACKS:

firm input:	1	2
1	0.000	0.000
2	34159.404	0.000
3	0.000	0.000
4	0.000	529.325
5	0.000	0.000
6	0.000	0.000
7	0.000	373426.723
8	0.000	3699.168
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000
15	0.000	0.000
16	0.000	16824.323
17	0.000	0.000
18	0.000	0.000
19	0.000	0.000
20	0.000	0.000
21	0.000	0.000
22	0.000	0.000
23	7240.550	0.000
24	0.000	0.000
25	0.000	0.000
26	0.000	0.000
27	0.000	0.000
28	0.000	0.000

29	0.000	0.000
30	0.000	0.000
31	0.000	0.000
32	0.000	0.000
33	0.000	0.000
34	0.000	0.000
35	0.000	0.000
36	0.000	0.000
37	96123.913	952.236
38	0.000	0.000
39	0.000	0.000
40	0.000	0.000
mean	3438.097	9885.794

SUMMARY OF PEERS:

firm	peers:					
1	27	32	40	6	17	39
2	3	15	27	30	40	
3	3					
4	12	17				
5	5					
6	6					
7	17	21	26	25		
8	17	6				
9	6	12	17	40		
10	24	6	12			
11	17	39	28	12		
12	12					
13	13					
14	14					
15	15					
16	6	17	12			
17	17					
18	18					
19	6	12	13			
20	3	30	21	17	36	
21	21					
22	6	12				
23	13	6				
24	24					
25	25					
26	26					
27	27					
28	28					
29	29					
30	30					

31	31			
32	32			
33	33			
34	34			
35	36	14	15	25
36	36			
37	25	26		
38	14	17	25	5
39	39			
40	40			

SUMMARY OF PEER WEIGHTS:
(in same order as above)

firm	peer weights:					
1	0.179	0.259	0.021	0.204	0.242	0.094
2	0.004	0.158	0.089	0.673	0.077	
3	1.000					
4	0.556	0.444				
5	1.000					
6	1.000					
7	0.112	0.402	0.433	0.053		
8	0.311	0.689				
9	0.621	0.302	0.066	0.011		
10	0.205	0.067	0.728			
11	0.384	0.004	0.099	0.514		
12	1.000					
13	1.000					
14	1.000					
15	1.000					
16	0.322	0.615	0.063			
17	1.000					
18	1.000					
19	0.539	0.240	0.221			
20	0.231	0.674	0.053	0.021	0.021	
21	1.000					
22	0.408	0.592				
23	0.297	0.703				
24	1.000					
25	1.000					
26	1.000					
27	1.000					
28	1.000					
29	1.000					
30	1.000					
31	1.000					
32	1.000					
33	1.000					

34	1.000			
35	0.207	0.036	0.253	0.504
36	1.000			
37	0.604	0.396		
38	0.501	0.154	0.175	0.170
39	1.000			
40	1.000			

PEER COUNT SUMMARY:
(i.e., no. times each firm is a peer for another)

firm	peer count:
1	0
2	0
3	2
4	0
5	1
6	8
7	0
8	0
9	0
10	0
11	0
12	7
13	2
14	2
15	2
16	0
17	9
18	0
19	0
20	0
21	2
22	0
23	0
24	1
25	4
26	2
27	2
28	1
29	0
30	2
31	0
32	1
33	0
34	0
35	0
36	2

37	0
38	0
39	2
40	3

SUMMARY OF OUTPUT TARGETS:

firm	output: 1	2	3	4	5
1	12.943	140769.861	202564.449	30.655	69.825
2	33.915	280456.253	658528.785	64.750	122.916
3	42.000	263600.000	1820000.000	100.000	210.000
4	13.995	122818.024	302632.804	29.445	58.891
5	12.040	110778.000	388833.000	32.000	62.000
6	3.080	24018.000	6782.000	26.000	28.000
7	42.887	401733.571	1349422.451	97.425	235.994
8	11.175	92112.994	213419.113	33.475	50.425
9	4.613	40849.214	52456.529	24.404	33.791
10	2.188	25682.308	12371.430	13.045	24.284
11	14.867	133605.670	305324.056	29.873	67.215
12	1.934	26941.000	8520.000	13.000	26.000
13	4.040	34686.000	28040.000	12.000	29.000
14	33.000	210000.000	2700000.000	71.000	176.000
15	47.180	326317.000	2270000.000	150.000	220.000
16	18.993	158670.908	414943.849	39.944	72.158
17	29.070	242651.000	670233.000	50.000	100.000
18	73.940	517585.000	1551471.000	88.000	208.000
19	3.016	27076.180	11893.510	19.783	27.740
20	37.013	301086.992	754053.781	61.057	132.500
21	34.700	389939.000	286820.000	100.000	242.000
22	2.402	25748.048	7810.677	18.306	26.816
23	3.365	27185.911	13094.660	21.843	28.297
24	2.800	21764.000	27828.000	9.000	17.000
25	51.500	316000.000	4200000.000	100.000	160.000
26	53.000	464432.000	2160000.000	107.000	275.000
27	11.120	95097.000	50000.000	35.000	78.000
28	26.800	264738.000	433500.000	40.000	153.000
29	2.400	20300.000	45000.000	15.000	11.000
30	35.600	307866.000	415000.000	45.000	99.000
31	7.526	197202.000	942279.000	9.000	34.000
32	4.473	170946.000	22000.000	14.000	49.000
33	9.080	188140.000	67443.000	10.000	39.000
34	16.778	254914.000	228414.000	48.000	108.000
35	47.559	317537.438	3024384.287	103.295	165.366
36	40.975	329214.000	1144458.000	60.000	110.000
37	52.095	374847.294	3391222.374	102.775	205.593
38	32.061	216668.864	2256111.278	66.195	142.070
39	18.560	130887.000	230088.000	14.000	100.000

40	17.700	160570.000	116655.000	95.000	180.000

SUMMARY OF INPUT TARGETS:

firm	input: 1	2
1	105300.000	28172.000
2	515207.596	70000.000
3	1046220.000	125000.000
4	53700.000	29970.675
5	62120.000	32866.000
6	16851.000	1000.000
7	563000.000	287145.277
8	45863.000	21300.832
9	24000.000	5950.000
10	11430.000	1000.000
11	65365.000	36927.000
12	8655.000	1000.000
13	70423.000	1000.000
14	670640.000	166911.000
15	1444474.000	175190.000
16	73627.000	41088.677
17	110000.000	66180.000
18	1046000.000	398586.000
19	26709.000	1000.000
20	514694.000	75000.000
21	473750.000	115000.000
22	12000.000	1000.000
23	32759.450	1000.000
24	19500.000	1000.000
25	710000.000	442000.000
26	745000.000	485000.000
27	210000.000	11250.000
28	184000.000	110000.000
29	12470.000	4650.000
30	354000.000	53850.000
31	110000.000	176579.000
32	65000.000	18500.000
33	61000.000	22690.000
34	135138.000	96156.000
35	813300.000	295800.000
36	320000.000	110000.000
37	723876.087	459047.764
38	487500.000	176700.000
39	144000.000	41000.000
40	340000.000	60000.000

APPENDIX 7

Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file = eg8-dta.txt

Output orientated DEA

Scale assumption: VRS

Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm	crste	vrste	scale	
1	0.306	0.696	0.439	drs
2	0.497	1.000	0.497	drs
3	0.339	0.696	0.487	drs
4	1.000	1.000	1.000	-
5	1.000	1.000	1.000	-
6	0.315	0.508	0.620	drs
7	0.424	0.538	0.789	drs
8	0.568	0.568	1.000	-
9	0.584	0.806	0.725	drs
10	1.000	1.000	1.000	-
11	1.000	1.000	1.000	-
12	0.624	0.776	0.804	drs
13	1.000	1.000	1.000	-
14	0.748	0.748	1.000	-
15	0.433	0.433	1.000	-
16	0.458	0.458	1.000	-
17	1.000	1.000	1.000	-
mean	0.664	0.778	0.845	

Note: crste = technical efficiency from CRS DEA
vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm	output:	1	2	3	4	5

1	3.526	2610.108	178414.324	2.255	0.000
2	0.000	0.000	0.000	0.000	0.000
3	7.761	64761.634	244017.668	2.155	0.000
4	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000
6	6.213	43143.019	135963.889	0.000	5.135
7	1.243	9603.176	15832.176	3.631	0.000
8	0.000	548.604	0.000	0.721	4.918
9	5.062	28449.431	211841.335	4.965	0.000
10	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000
12	4.059	15021.790	127887.855	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000
14	0.208	7784.807	0.000	3.794	0.000
15	0.000	4902.387	3150.569	11.371	12.947
16	1.694	7372.456	0.000	0.000	19.560
17	0.000	0.000	0.000	0.000	0.000
mean	1.751	10835.142	53947.519	1.700	2.504

SUMMARY OF INPUT SLACKS:

firm input:	1	2
1	0.000	0.000
2	0.000	0.000
3	0.000	529.325
4	0.000	0.000
5	0.000	0.000
6	0.000	3699.168
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	16824.323
13	0.000	0.000
14	0.000	0.000
15	0.000	0.000
16	7240.550	0.000
17	0.000	0.000
mean	425.915	1238.401

SUMMARY OF PEERS:

firm	peers:		
1	2	11	13

2	2		
3	13	10	
4	4		
5	5		
6	13	5	
7	5	11	13
8	10	17	5
9	5	13	10
10	10		
11	11		
12	13	10	5
13	13		
14	11	5	10
15	10	5	
16	5	11	
17	17		

SUMMARY OF PEER WEIGHTS:
(in same order as above)

firm	peer weights:		
1	0.042	0.586	0.372
2	1.000		
3	0.444	0.556	
4	1.000		
5	1.000		
6	0.311	0.689	
7	0.923	0.001	0.076
8	0.728	0.205	0.067
9	0.104	0.551	0.345
10	1.000		
11	1.000		
12	0.615	0.063	0.322
13	1.000		
14	0.162	0.127	0.711
15	0.592	0.408	
16	0.703	0.297	
17	1.000		

PEER COUNT SUMMARY:
(i.e., no. times each firm is a peer for another)

firm	peer count:
1	0
2	1
3	0
4	0

5	8
6	0
7	0
8	0
9	0
10	6
11	4
12	0
13	6
14	0
15	0
16	0
17	1

SUMMARY OF OUTPUT TARGETS:

firm	output: 1	2	3	4	5
1	14.449	121411.537	291220.921	28.126	58.928
2	29.940	255549.000	600045.000	59.000	112.000
3	13.995	122818.024	302632.804	29.445	58.891
4	12.040	110778.000	388833.000	32.000	62.000
5	3.080	24018.000	6782.000	26.000	28.000
6	11.175	92112.994	213419.113	33.475	50.425
7	5.055	40636.686	57196.553	27.803	33.469
8	2.188	25682.308	12371.430	13.045	24.284
9	17.010	145536.862	373073.984	34.741	66.996
10	1.934	26941.000	8520.000	13.000	26.000
11	4.040	34686.000	28040.000	12.000	29.000
12	18.993	158670.908	414943.849	39.944	72.158
13	29.070	242651.000	670233.000	50.000	100.000
14	2.421	27825.678	11465.106	14.490	26.741
15	2.402	25748.048	7810.677	18.306	26.816
16	3.365	27185.911	13094.660	21.843	28.297
17	2.800	21764.000	27828.000	9.000	17.000

SUMMARY OF INPUT TARGETS:

firm	input: 1	2
1	105300.000	28172.000
2	549367.000	70000.000
3	53700.000	29970.675
4	62120.000	32866.000
5	16851.000	1000.000
6	45863.000	21300.832
7	24000.000	5950.000
8	11430.000	1000.000

9	65365.000	36927.000
10	8655.000	1000.000
11	70423.000	1000.000
12	73627.000	41088.677
13	110000.000	66180.000
14	19715.000	1000.000
15	12000.000	1000.000
16	32759.450	1000.000
17	19500.000	1000.000

APPENDIX 8

Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file = eg6-dta.txt

Output orientated DEA

Scale assumption: VRS

Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm	crste	vrste	scale	
1	0.702	0.709	0.991	drs
2	0.789	0.856	0.921	drs
3	0.665	0.890	0.747	drs
4	0.691	0.730	0.947	drs
5	1.000	1.000	1.000	-
6	1.000	1.000	1.000	-
7	0.624	0.788	0.791	drs
8	0.548	0.558	0.981	drs
9	0.767	0.771	0.995	irs
10	0.872	1.000	0.872	irs
11	0.627	0.758	0.827	drs
12	1.000	1.000	1.000	-
13	0.627	0.642	0.977	drs
14	0.661	0.935	0.707	drs
15	0.625	0.840	0.745	drs
16	0.799	0.803	0.995	irs
17	0.921	1.000	0.921	drs
18	0.696	1.000	0.696	drs
19	0.570	0.577	0.988	irs
20	0.648	0.758	0.855	drs
21	0.689	1.000	0.689	drs
22	0.971	1.000	0.971	irs
23	0.565	0.566	0.998	drs
24	1.000	1.000	1.000	-
25	0.832	1.000	0.832	drs
26	0.774	1.000	0.774	drs
27	0.927	0.946	0.979	drs
28	0.810	1.000	0.810	drs
29	0.799	0.835	0.956	irs
30	0.955	1.000	0.955	drs
31	0.957	1.000	0.957	drs

32	1.000	1.000	1.000	-
33	0.968	1.000	0.968	drs
34	0.726	1.000	0.726	drs
35	0.863	1.000	0.863	drs
36	1.000	1.000	1.000	-
37	1.000	1.000	1.000	-
38	1.000	1.000	1.000	-
39	0.766	0.842	0.910	drs
40	0.823	0.904	0.910	drs
mean	0.806	0.893	0.906	

Note: crste = technical efficiency from CRS DEA
vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm	output: 1	2
1	0.000	0.000
2	0.000	0.000
3	0.000	4.793
4	0.000	0.000
5	0.000	0.000
6	0.000	0.000
7	0.000	5.947
8	0.000	0.000
9	0.000	3.337
10	0.000	0.000
11	8.915	0.000
12	0.000	0.000
13	0.000	1.770
14	0.000	7.344
15	0.000	23.913
16	0.000	0.967
17	0.000	0.000
18	0.000	0.000
19	0.000	2.725
20	0.000	0.000
21	0.000	0.000
22	0.000	0.000
23	0.000	0.000
24	0.000	0.000
25	0.000	0.000
26	0.000	0.000

27	0.000	0.000
28	0.000	0.000
29	0.000	0.678
30	0.000	0.000
31	0.000	0.000
32	0.000	0.000
33	0.000	0.000
34	0.000	0.000
35	0.000	0.000
36	0.000	0.000
37	0.000	0.000
38	0.000	0.000
39	0.000	0.000
40	2364.393	0.000
mean	59.333	1.287

SUMMARY OF INPUT SLACKS:

firm input:	1	2	3
1	0.000	0.000	1785.554
2	0.000	0.000	99178.023
3	75.882	0.000	327984.706
4	6.695	0.000	959.125
5	0.000	0.000	0.000
6	0.000	0.000	0.000
7	32.304	0.000	0.000
8	0.000	0.000	0.000
9	0.000	7.964	0.000
10	0.000	0.000	0.000
11	0.000	0.000	0.000
12	0.000	0.000	0.000
13	0.000	0.000	0.000
14	118.868	0.000	0.000
15	0.000	0.000	689992.457
16	0.000	0.000	0.000
17	0.000	0.000	0.000
18	0.000	0.000	0.000
19	0.000	0.709	0.000
20	0.000	0.000	7460.645
21	0.000	0.000	0.000
22	0.000	0.000	0.000
23	0.000	0.000	17463.480
24	0.000	0.000	0.000
25	0.000	0.000	0.000
26	0.000	0.000	0.000
27	0.000	0.000	58596.517
28	0.000	0.000	0.000

29	1.294	0.069	0.000
30	0.000	0.000	0.000
31	0.000	0.000	0.000
32	0.000	0.000	0.000
33	0.000	0.000	0.000
34	0.000	0.000	0.000
35	0.000	0.000	0.000
36	0.000	0.000	0.000
37	0.000	0.000	0.000
38	0.000	0.000	0.000
39	0.000	0.000	0.000
40	0.000	0.000	15020.659
mean	5.876	0.219	30461.029

SUMMARY OF PEERS:

firm	peers:				
1	30	32	38	6	
2	30	35	36	38	
3	26	25			
4	38	30	6		
5	5				
6	6				
7	30	36	25		
8	36	38	6	32	30
9	6	5	12		
10	10				
11	28	32	34	6	
12	12				
13	6	38	30	36	
14	26	25	36		
15	26	25	35		
16	32	36	5	24	
17	17				
18	18				
19	6	5	12		
20	36	26	25	30	
21	21				
22	22				
23	32	38	6	24	
24	24				
25	25				
26	26				
27	38	32	30	6	
28	28				
29	6	12			
30	30				

31	31				
32	32				
33	33				
34	34				
35	35				
36	36				
37	37				
38	38				
39	30	28	6	17	5
40	30	37	32		

SUMMARY OF PEER WEIGHTS:
(in same order as above)

firm	peer weights:				
1	0.061	0.791	0.059	0.089	
2	0.344	0.191	0.319	0.146	
3	0.235	0.765			
4	0.063	0.018	0.919		
5	1.000				
6	1.000				
7	0.009	0.369	0.622		
8	0.011	0.036	0.859	0.080	0.014
9	0.502	0.210	0.288		
10	1.000				
11	0.156	0.059	0.166	0.619	
12	1.000				
13	0.864	0.066	0.040	0.031	
14	0.299	0.573	0.128		
15	0.603	0.171	0.226		
16	0.671	0.066	0.091	0.172	
17	1.000				
18	1.000				
19	0.050	0.330	0.620		
20	0.319	0.038	0.419	0.224	
21	1.000				
22	1.000				
23	0.011	0.006	0.185	0.797	
24	1.000				
25	1.000				
26	1.000				
27	0.149	0.213	0.160	0.477	
28	1.000				
29	0.465	0.535			
30	1.000				
31	1.000				
32	1.000				
33	1.000				

```
  34   1.000
  35   1.000
  36   1.000
  37   1.000
  38   1.000
  39   0.249 0.074 0.073 0.073 0.531
  40   0.757 0.055 0.189


PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
    1       0
    2       0
    3       0
    4       0
    5       4
    6      11
    7       0
    8       0
    9       0
   10       0
   11       0
   12       3
   13       0
   14       0
   15       0
   16       0
   17       1
   18       0
   19       0
   20       0
   21       0
   22       0
   23       0
   24       2
   25       5
   26       4
   27       0
   28       2
   29       0
   30      10
   31       0
   32       7
   33       0
   34       1
   35       2
   36       7
```

37	1
38	7
39	0
40	0

SUMMARY OF OUTPUT TARGETS:

firm	output: 1	2
1	3373.407	28.218
2	12263.837	70.079
3	13957.412	72.176
4	2192.506	13.703
5	3375.000	27.000
6	1500.000	10.000
7	13548.878	69.378
8	2148.830	14.326
9	1634.748	12.419
10	720.000	6.000
11	3097.653	23.760
12	600.000	6.000
13	2803.738	17.346
14	14198.939	76.847
15	14888.575	85.850
16	3106.178	25.866
17	6230.000	40.000
18	18571.000	100.000
19	1560.770	13.130
20	13170.149	72.588
21	10320.000	86.000
22	720.000	6.000
23	1324.693	8.831
24	1200.000	8.000
25	13348.000	63.000
26	15938.000	102.000
27	4497.304	29.588
28	6580.000	50.000
29	1018.924	7.862
30	11274.000	75.000
31	3000.000	30.000
32	2500.000	25.000
33	2400.000	30.000
34	6000.000	50.000
35	13251.000	60.000
36	13940.000	80.000
37	14296.000	90.000
38	9655.000	50.000
39	5651.194	40.366

40	9784.864	66.393

SUMMARY OF INPUT TARGETS:

firm	input: 1	2	3
1	62.000	45.000	103514.446
2	250.000	128.000	450188.977
3	387.118	137.000	718235.294
4	50.305	17.000	52740.875
5	59.000	52.000	62120.000
6	37.000	11.000	16851.000
7	327.696	140.000	563000.000
8	48.000	19.000	45863.000
9	35.000	19.036	24000.000
10	24.000	8.000	11430.000
11	94.000	35.000	65365.000
12	14.000	9.000	8655.000
13	62.000	24.000	70423.000
14	373.132	148.000	670640.000
15	381.000	167.000	754481.543
16	53.000	46.000	73627.000
17	135.000	84.000	110000.000
18	452.000	328.000	1046000.000
19	30.000	23.291	26709.000
20	312.000	135.000	507233.355
21	270.000	199.000	473750.000
22	15.000	13.000	12000.000
23	30.000	11.000	22536.520
24	27.000	10.000	19500.000
25	377.000	121.000	710000.000
26	420.000	189.000	745000.000
27	96.000	42.000	151403.483
28	228.000	68.000	184000.000
29	24.706	9.931	12470.000
30	266.000	98.000	354000.000
31	96.000	40.000	110000.000
32	40.000	42.000	65000.000
33	62.000	68.000	61000.000
34	200.000	91.000	135138.000
35	280.000	143.000	813300.000
36	246.000	173.000	320000.000
37	204.000	218.000	820000.000
38	182.000	81.000	487500.000
39	127.000	64.000	144000.000
40	220.000	94.000	324979.341

APPENDIX 9

Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file = eg9-dta.txt

Output orientated DEA

Scale assumption: VRS

Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm	crste	vrste	scale	
1	0.789	0.900	0.877	irs
2	0.797	0.856	0.931	drs
3	0.761	0.890	0.855	drs
4	1.000	1.000	1.000	-
5	0.666	0.788	0.845	drs
6	0.841	1.000	0.841	irs
7	0.769	0.935	0.823	drs
8	0.628	0.840	0.748	drs
9	0.832	1.000	0.832	irs
10	1.000	1.000	1.000	-
11	0.696	1.000	0.696	drs
12	0.682	0.758	0.900	drs
13	0.773	1.000	0.773	drs
14	0.927	1.000	0.927	drs
15	0.807	1.000	0.807	drs
16	0.971	1.000	0.971	irs
17	1.000	1.000	1.000	-
18	1.000	1.000	1.000	-
19	1.000	1.000	1.000	-
20	1.000	1.000	1.000	-
21	0.978	1.000	0.978	drs
22	0.863	1.000	0.863	drs
23	1.000	1.000	1.000	-
24	1.000	1.000	1.000	-
25	1.000	1.000	1.000	-
26	0.849	0.858	0.989	irs
27	0.873	0.913	0.956	drs
mean	0.870	0.953	0.912	

Note: crste = technical efficiency from CRS DEA

vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm	output: 1	2
1	0.000	0.000
2	0.000	0.000
3	0.000	4.793
4	0.000	0.000
5	0.000	5.947
6	0.000	0.000
7	0.000	7.344
8	0.000	23.913
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000
15	0.000	0.000
16	0.000	0.000
17	0.000	0.000
18	0.000	0.000
19	0.000	0.000
20	0.000	0.000
21	0.000	0.000
22	0.000	0.000
23	0.000	0.000
24	0.000	0.000
25	0.000	0.000
26	0.000	0.872
27	2426.230	0.000
mean	89.860	1.588

SUMMARY OF INPUT SLACKS:

firm	input: 1	2	3
1	0.000	0.000	22135.158
2	0.000	0.000	99178.023
3	75.882	0.000	327984.706
4	0.000	0.000	0.000
5	32.304	0.000	0.000

6	0.000	0.000	0.000
7	118.868	0.000	0.000
8	0.000	0.000	689992.457
9	0.000	0.000	0.000
10	0.000	0.000	0.000
11	0.000	0.000	0.000
12	0.000	0.000	7460.645
13	0.000	0.000	0.000
14	0.000	0.000	0.000
15	0.000	0.000	0.000
16	0.000	0.000	0.000
17	0.000	0.000	0.000
18	0.000	0.000	0.000
19	0.000	0.000	0.000
20	0.000	0.000	0.000
21	0.000	0.000	0.000
22	0.000	0.000	0.000
23	0.000	0.000	0.000
24	0.000	0.000	0.000
25	0.000	0.000	0.000
26	0.000	0.000	0.000
27	0.000	0.000	25121.618
mean	8.409	0.000	43402.689

SUMMARY OF PEERS:

firm	peers:			
1	16	19	4	9
2	22	23	18	25
3	15	14		
4	4			
5	23	14	18	
6	6			
7	15	14	23	
8	22	15	14	
9	9			
10	10			
11	11			
12	18	15	23	14
13	13			
14	14			
15	15			
16	16			
17	17			
18	18			
19	19			
20	20			

```
  21     21
  22     22
  23     23
  24     24
  25     25
  26      6   17   18    4
  27     18   24    4
```

SUMMARY OF PEER WEIGHTS:
(in same order as above)

```
 firm  peer weights:
   1   0.024 0.181 0.030 0.765
   2   0.191 0.319 0.344 0.146
   3   0.235 0.765
   4   1.000
   5   0.369 0.622 0.009
   6   1.000
   7   0.299 0.573 0.128
   8   0.226 0.603 0.171
   9   1.000
  10   1.000
  11   1.000
  12   0.224 0.038 0.319 0.419
  13   1.000
  14   1.000
  15   1.000
  16   1.000
  17   1.000
  18   1.000
  19   1.000
  20   1.000
  21   1.000
  22   1.000
  23   1.000
  24   1.000
  25   1.000
  26   0.032 0.108 0.235 0.625
  27   0.745 0.047 0.208
```

PEER COUNT SUMMARY:
(i.e., no. times each firm is a peer for another)

```
 firm  peer count:
   1       0
   2       0
   3       0
```

4	3
5	0
6	1
7	0
8	0
9	1
10	0
11	0
12	0
13	0
14	5
15	4
16	1
17	1
18	5
19	1
20	0
21	0
22	2
23	4
24	1
25	1
26	0
27	0

SUMMARY OF OUTPUT TARGETS:

firm	output: 1	2
1	2655.728	22.214
2	12263.837	70.079
3	13957.412	72.176
4	3375.000	27.000
5	13548.878	69.378
6	2340.000	18.000
7	14198.939	76.847
8	14888.575	85.850
9	2495.000	20.000
10	6230.000	40.000
11	18571.000	100.000
12	13170.149	72.588
13	10320.000	86.000
14	13348.000	63.000
15	15938.000	102.000
16	4256.000	28.000
17	6580.000	50.000
18	11274.000	75.000
19	3000.000	30.000

20	2400.000	30.000
21	6000.000	50.000
22	13251.000	60.000
23	13940.000	80.000
24	14296.000	90.000
25	9655.000	50.000
26	5544.991	40.479
27	9769.266	65.700

SUMMARY OF INPUT TARGETS:

firm input:	1	2	3
1	62.000	45.000	83164.842
2	250.000	128.000	450188.977
3	387.118	137.000	718235.294
4	59.000	52.000	62120.000
5	327.696	140.000	563000.000
6	94.000	35.000	65365.000
7	373.132	148.000	670640.000
8	381.000	167.000	754481.543
9	53.000	46.000	73627.000
10	135.000	84.000	110000.000
11	452.000	328.000	1046000.000
12	312.000	135.000	507233.355
13	270.000	199.000	473750.000
14	377.000	121.000	710000.000
15	420.000	189.000	745000.000
16	96.000	42.000	210000.000
17	228.000	68.000	184000.000
18	266.000	98.000	354000.000
19	96.000	40.000	110000.000
20	62.000	68.000	61000.000
21	200.000	91.000	135138.000
22	280.000	143.000	813300.000
23	246.000	173.000	320000.000
24	204.000	218.000	820000.000
25	182.000	81.000	487500.000
26	127.000	64.000	144000.000
27	220.000	94.000	314878.382

APPENDIX 10

Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file = eg10-dta.txt

Output orientated DEA

Scale assumption: VRS

Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm	crste	vrste	scale	
1	0.762	0.828	0.921	drs
2	0.875	1.000	0.875	drs
3	0.692	0.816	0.848	drs
4	1.000	1.000	1.000	-
5	1.000	1.000	1.000	-
6	0.555	0.598	0.928	drs
7	0.767	0.771	0.995	irs
8	0.872	1.000	0.872	irs
9	0.629	0.899	0.700	drs
10	1.000	1.000	1.000	-
11	0.647	0.726	0.891	drs
12	0.830	0.832	0.999	irs
13	0.922	1.000	0.922	drs
14	0.570	0.577	0.988	irs
15	0.971	1.000	0.971	irs
16	0.565	0.572	0.988	drs
17	1.000	1.000	1.000	-
mean	0.803	0.860	0.935	

Note: crste = technical efficiency from CRS DEA
vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm output: 1 2

1	330.146	0.000
2	0.000	0.000
3	0.000	0.304
4	0.000	0.000
5	0.000	0.000
6	21.274	0.000
7	0.000	3.337
8	0.000	0.000
9	192.539	0.000
10	0.000	0.000
11	0.000	1.754
12	0.000	0.000
13	0.000	0.000
14	0.000	2.725
15	0.000	0.000
16	0.000	0.081
17	0.000	0.000
mean	31.998	0.482

SUMMARY OF INPUT SLACKS:

firm input:	1	2	3
1	0.000	0.000	32768.986
2	0.000	0.000	0.000
3	9.077	0.000	9540.487
4	0.000	0.000	0.000
5	0.000	0.000	0.000
6	0.000	0.000	2170.131
7	0.000	7.964	0.000
8	0.000	0.000	0.000
9	35.923	0.000	0.000
10	0.000	0.000	0.000
11	2.150	0.000	0.000
12	0.000	0.000	18711.043
13	0.000	0.000	0.000
14	0.000	0.709	0.000
15	0.000	0.000	0.000
16	0.000	0.000	20372.851
17	0.000	0.000	0.000
mean	2.774	0.510	4915.500

SUMMARY OF PEERS:

firm	peers:		
1	2	4	5

```
  2      2
  3      2    5
  4      4
  5      5
  6      4    2    5
  7      5    4   10
  8      8
  9      5    2    4
 10     10
 11      5    2   13
 12      4   10   15   17
 13     13
 14      5   10    4
 15     15
 16     17    5    4
 17     17


SUMMARY OF PEER WEIGHTS:
  (in same order as above)

 firm  peer weights:
   1   0.045 0.701 0.254
   2   1.000
   3   0.051 0.949
   4   1.000
   5   1.000
   6   0.068 0.045 0.888
   7   0.502 0.210 0.288
   8   1.000
   9   0.516 0.055 0.430
  10   1.000
  11   0.880 0.097 0.023
  12   0.857 0.077 0.034 0.033
  13   1.000
  14   0.050 0.620 0.330
  15   1.000
  16   0.740 0.242 0.018
  17   1.000


PEER COUNT SUMMARY:
  (i.e., no. times each firm is a peer for another)

 firm  peer count:
   1       0
   2       5
   3       0
   4       7
```

5	8
6	0
7	0
8	0
9	0
10	3
11	0
12	0
13	1
14	0
15	1
16	0
17	2

SUMMARY OF OUTPUT TARGETS:

firm	output: 1	2
1	3219.009	24.164
2	10500.000	60.000
3	1961.538	12.564
4	3375.000	27.000
5	1500.000	10.000
6	2028.799	13.384
7	1634.748	12.419
8	720.000	6.000
9	2796.755	20.032
10	600.000	6.000
11	2479.277	15.528
12	3000.449	24.052
13	6230.000	40.000
14	1560.770	13.130
15	720.000	6.000
16	1311.920	8.827
17	1200.000	8.000

SUMMARY OF INPUT TARGETS:

firm	input: 1	2	3
1	62.000	45.000	72531.014
2	250.000	128.000	549367.000
3	47.923	17.000	44159.513
4	59.000	52.000	62120.000
5	37.000	11.000	16851.000
6	48.000	19.000	43692.869
7	35.000	19.036	24000.000
8	24.000	8.000	11430.000

9	58.077	35.000	65365.000
10	14.000	9.000	8655.000
11	59.850	24.000	70423.000
12	53.000	46.000	54915.957
13	135.000	84.000	110000.000
14	30.000	23.291	26709.000
15	15.000	13.000	12000.000
16	30.000	11.000	19627.149
17	27.000	10.000	19500.000

APPENDIX 11

MASTER DATA - ANNUAL FOR THE YEAR 2011-12								
Airport	**Annual PAX (MPPA)**	**Annual ATM**	**Cargo (Ton)**	**No. of Airlines**	**No. of Destinations**	**Area of Pax terminal**	**Area of Cargo Terminal**	**ASQ Score**
Hyderabad	8.4	99013	78099	18	41	105300	28172	**4.6**
Delhi	35.9	317283	568354	59	112	549367	70000	**4.81**
Changi	46.5	301700	1898000	100	210	1046220	125000	**4.86**
Cochin	4.7	40429	42706	19	41	53700	30500	**NP**
Chennai	12.9	120127	357191	32	62	144000	32866	**3.07**
Goa	3.5	24018	6170	26	28	16851	1000	**4.08**
Bangkok	47.9	299566	1321000	97	177	563000	660572	**4.38**
Trivandrum	2.8	24869	27229	17	23	45863	25000	**3.52**
Calicut	2.2	16696	16150	13	18	24000	5950	**3.88**
Coimbatore	1.3	14572	7748	7	11	11430	1000	**NP**
Kolkata	10.3	99843	125593	24	54	180000	36927	**2.87**
Guwahati	2.2	26941	7761	13	26	8655	1000	**3.53**
Ahmedabad	4.7	40506	31757	12	29	70423	1000	**3.39**
Incheon	35.2	229580	2539000	71	176	670640	166911	**4.91**
Dubai	51	326317	2270000	150	220	1444474	175190	**4.47**
Bangalore	12.7	118431	224949	31	56	73627	57913	**4.23**
Mumbai	30.7	251492	657470	50	100	110000	66180	**4.65**
Beijing	77.4	533253	1668000	88	208	1046000	398586	**4.88**
Jaipur	1.8	18603	6710	8	20	26709	1000	**4.12**
Kuala Lumpur	37.7	269509	702116	55	122	514694	75000	**4.56**
Munich	37.8	409956	320430	100	242	473750	115000	**4.05**
Srinagar	1.6	12187	2361	3	6	12000	1000	**NP**
Amritsar	0.9	9208	7087	10	4	40000	1000	**NP**
Pune	3.29	27110	24134	9	17	19500	1000	**4.17**
Hongkong	54.9	339000	3900000	100	160	710000	442000	**4.79**
Frankfurt	56.4	487162	2231348	107	275	745000	485000	**3.77**
SGI	13.7	104000	50000	35	78	210000	11250	**NP**
Brazil	30	270601	465256	40	153	184000	110000	**NP**
Male'	2.6	22330	45000	15	11	12470	4650	**NP**
Sydney	36	307866	471000	45	99	354000	53850	**4.04**
Indianapolis	7.4	159697	1001400	9	34	110000	176579	**4.48**
Ottawa	4.6	172115	22000	14	49	65000	18500	**4.47**
Austin Bergstrom	9.1	176331	76685	10	39	61000	22690	**4.33**
Vancouver Intl	17	298483	228414	48	108	135138	96156	**NP**
Narita Intl	28.1	183450	1898885	55	92	813300	295800	**4.49**
Baiyun China	45.4	351066	1193000	60	110	320000	110000	**4.68**
Pu Dong Airport	41.5	344086	3103000	87	194	820000	460000	**4.69**
Taiwan Taoyuan	24.9	163199	1627000	50	75	487500	176700	**4.41**
Stansted	18.1	138792	231257	14	100	144000	41000	**3.74**

Manchester	19.31	168406	106916	95	180	340000	60000	**3.97**

APPENDIX 12

MASTER DATA -PEAK HOUR TRAFFIC FOR THE YEAR 2011-12						
Airport	Peak Pax	Peak ATM	Check-in	Apron Bays	Area of Pax terminal	ASQ Score
Hyderabad	2439	22	62	45	105300	**4.6**
Delhi	10710	66	250	128	549367	**4.81**
Changi	12677	66	463	137	1046220	**4.86**
Cochin	1632	11	57	17	53700	**NP**
Chennai	3443	30	140	94	144000	**3.07**
Goa	1530	11	37	11	16851	**4.08**
Bangkok	10894	55	360	140	563000	**4.38**
Trivandrum	1224	9	48	19	45863	**3.52**
Calicut	1285	8	35	27	24000	**3.88**
Coimbatore	734	7	24	8	11430	**NP**
Kolkata	2387	20	128	71	180000	**2.87**
Guwahati	612	7	14	9	8655	**3.53**
Ahmedabad	1836	11	62	24	70423	**3.39**
Incheon	13545	72	492	148	670640	**4.91**
Dubai	12750	57	381	167	1444474	**4.47**
Bangalore	2545	22	53	46	73627	**4.23**
Mumbai	6355	44	135	84	110000	**4.65**
Beijing	18942	110	452	328	1046000	**4.88**
Jaipur	918	7	30	24	26709	**4.12**
Kuala Lumpur	10179	61	312	135	514694	**4.56**
Munich	10526	95	270	199	473750	**4.05**
Srinagar	734	7	15	13	12000	**NP**
Amritsar	765	6	30	11	40000	**NP**
Pune	1224	9	27	10	19500	**4.17**
Hongkong	13615	69	377	121	710000	**4.79**
Frankfurt	16257	112	420	189	745000	**3.77**
SGI	4341	31	96	42	210000	**NP**
Brazil	6712	55	228	68	184000	**NP**
Male'	868	7	26	10	12470	**NP**
Sydney	11499	83	266	98	354000	**4.04**
Indianapolis	3060	33	96	40	110000	**4.48**
Ottawa	2550	28	40	42	65000	**4.47**
Austin Bergstrom	2448	33	62	68	61000	**4.33**
Vancouver Intl	6120	55	200	91	135138	**NP**
Narita Intl	13516	66	280	143	813300	**4.49**
Baiyun China	14219	88	246	173	320000	**4.68**
Pu Dong Airport	14582	99	204	218	820000	**4.69**
Taiwan Taoyuan	9848	55	182	81	487500	**4.41**
Stansted	4855	37	127	64	144000	**3.74**
Manchester	6840	66	220	94	340000	**3.97**

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