1006

Rico Merkert and Romano Pagliari (Cranfield University), James Odeck, Svein Bråthen, Nigel Halpern and Jan Husdal

BENCHMARKING AVINOR'S EFFICIENCY – A PRESTUDY

MØREFORSKING MOLDE

Høgskolen i Molde

Rico Merkert and Romano Pagliari (Cranfield University), James Odeck,
Svein Bråthen, Nigel Halpern and Jan Husdal

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Author (s)	Rico Merkert and Romano Pagliari (Cranfield University), James Odeck, Svein Bråthen, Nigel Halpern and Jan Husdal
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Summary:

This report investigates ways of benchmarking Avinor's efficiency as an airport and air traffic service provider, up against an international sample of airports. The report recommends the following approach for a benchmarking study:

1. An internal benchmarking study of Avinor's airports, where one could apply a Partial Productivity Measures (PPM) study and/or a 2-stage Data Envelopment Analysis (DEA) study.
2. A PPM comparison between a selection of Avinor's airports and a number of comparable international airports.
3. A 2-stage DEA analysis on a larger set of airports. Data from around 150 airports in Northern Europe would be available.

We would like to recommend the third approach, however with the option to limit the study to the first and second approach.

Preface

The purpose of this work is to explore the possibilities for doing an international benchmark study of airport efficiency. The main objective is to consider the possibilities of benchmarking Avinor against comparable international airport service providers.

There are certain challenges with respect to data availability and choice of method for the analysis. These two aspects may be interrelated as well; data may give premises for the method, and vice versa. The report concludes on these matters.

This report is joint work between Cranfield University and Møreforsking Molde AS. Romano Pagliari, Rico Merkert and James Odeck have written most of Section 4. Jan Husdal has written most of Section 3. Nigel Halpern has provided valuable input in the discussions and in reporting on the availability of data from international airports. Svein Bråthen has coordinated the project and compiled the report including the rest of the sections.

Molde/Cranfield, 1st May 2010

The authors

CONTENTS

1 SUMMARY AND RECOMMENDATIONS

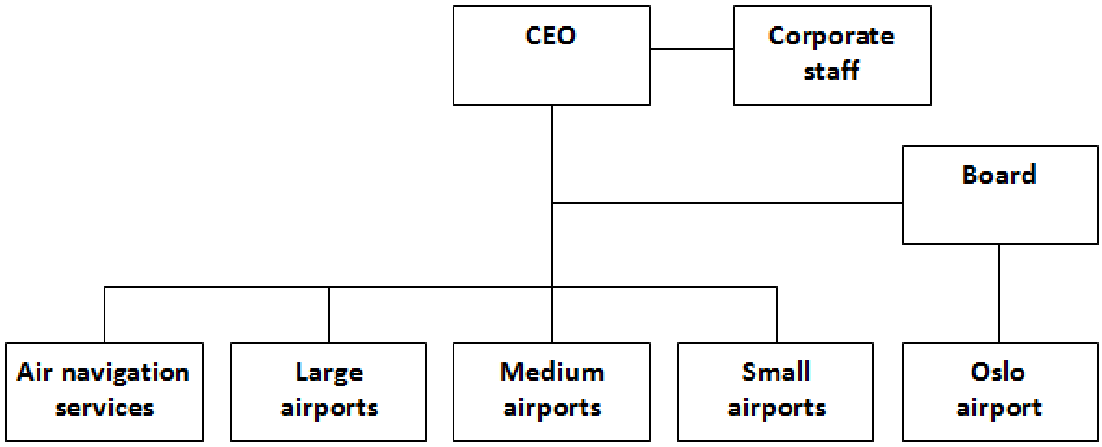
1.1 Point of departure

The purpose of this project is twofold:

- It should give an overview and an assessment of all studies that compare Avinor's cost efficiency with other providers of comparable services.
- The study should give directions for further research, including assessment of data availability and methodological challenges.

Avinor's organization plan is used as the point of departure for assessing how the efficiency issues for the various activities could be measured. The organization map is shown below.

Figure 1.1: The structure of Avinor



(Source: www.avinor.no, with our translation)

This structure is used as a base for the search for possible methods and data for a prospective main research project. Many operational units are placed underneath this superstructure, like air navigation services, ATC, and all the airports. There are also different profit centres underneath these sub units. However, there will be a question of how far we can go with this breakdown with respect to an international comparison. Doing the analysis on the right aggregation level would clearly influence the possibilities of obtaining data to do a robust comparison and to identify the important cost drivers. In this project, ANS services will be omitted from the analysis. Benchmarking of these services are done by Eurocontrol (Eurocontrol 2009).

Parts of Avinor's activities are done under various kinds of political objectives, which may affect the efficiency of Avinor's operations. These factors may be of particular interest when assessing the efficiency of the smaller airports. One might also have various local ways of organizing some of the operations. Winter-time maintenance and/or fire protection services can be provided in cooperation with the local authorities. This is a kind of outsourcing, and outsourcing may also be present in other parts of Avinor's system. In addition, some of the airports will have special attention towards non-airside activities, which also have to be taken into account.

1.2 Research Methods

1.2.1 Summary of the PPM approach

Applying partial indicators of performance is the traditional and most commonly used method to compare airports. Typically these studies focus on the following dimensions of airport performance:

- Cost efficiency
- Productivity
- Revenue generating capability
- Profitability

For each of these dimensions, measures have been developed which relate in some way the airport's inputs and outputs. The major inputs in an airport system are: labour and capital. Depending on the performance measure used, the inputs are measured in either physical or financial terms. For example, labour can be expressed in terms of number of employees or in terms of total labour costs incurred by the airport. Capital is usually measured in physical terms and can be represented by for example, the capacity of the runways or the amount of terminal space allocated to retail activities.

As far as output is concerned various measures can be used. Traffic represents the key output of an airport and there are typically three dimensions; passengers, freight or aircraft movements. For the majority of civil airports, the most important output is passenger traffic. However, some airports have substantial freight activity. The challenge for researchers in the partial performance field has been to devise robust and reliable measures of output that cover the different types of traffic. The Work Load Unit (WLU) was devised to solve this problem as it essentially combines passenger and freight volume into one aggregate measure of airport output.

Given that data is accessible, partial measures are intuitively very easy to compute, understand and interpret. Judgment would need to be made on whether to normalise the data as done in previous studies in order to take into account differences in the degree of outsourcing between airports. However, as the benchmarking exercise itself is measuring the outcome of managerial decision-making i.e cost-efficiency, out-sourcing services will have an effect on performance and should ideally be incorporated in the analysis.

One significant limitation with partial measures is that they are less effective in providing a robust assessment of an airport's overall performance especially within the context of measuring the performance of the airport in relation its optimum potential performance. More sophisticated techniques are able to do this.

1.2.2 Summary of the more sophisticated approach

From the preceding sections it appears that DEA is an appropriate method for assessing efficiency for Avinor. The main advantages of DEA over other methods and which are relevant for the assessment of Avinor are as follows:

- DEA is easy to grasp and understand for managers; the benchmark is other service providers providing the same type of services using the same types of inputs and, these other providers are observable and not derived from some assumed production function.
- DEA readily incorporates multiple inputs and outputs and, it does not require price data to calculate technical efficiency. This makes it especially suitable for analysing the efficiency of service production, where it is often difficult to assign prices to many of the outputs.
- It determines sources of inefficiency and efficiency levels and provides a means of decomposing economic (cost) efficiency into technical and allocative efficiency. Furthermore, technical efficiency is decomposed into scale and non-scale effects.
- DEA identifies the "peers" for units (airports) that are not efficient. It thus provides a set of role models that the inefficient units can look to in order to improve its operations. This makes DEA a very useful tool for benchmarking compared to other methods.
- DEA can be extended to study efficiency over time using the Malmquist productivity index. Thus its advantages over other methods are maintained even when efficiency is being studied over time.

Like any assessment method, DEA too is based on a number of assumptions and hence has some weaknesses that one needs to acknowledge. The main ones are follows:

- DEA is a deterministic rather than a statistical approach. Its results would therefore be sensitive to measurement errors. However, recently it has been proven that applying DEA together with bootstrapping takes account of statistical noise adequately.
- DEA only measures efficiency relative to best practice within a particular sample. Thus it is not meaningful to compare efficiency scores across samples or across different studies.
- DEA scores are sensitive to the number of inputs and outputs, and the sample size. Increasing the sample size will tend to reduce the average efficiency score because including more observations provides greater scope for DEA to find a comparison partner. Conversely, fewer observations relative to the number of inputs and outputs can inflate the efficiency scores. There are however ways of

dealing with this problem. A rule of thumb is that the number of units in the sample should be at least three times greater than the sum of the number of outputs and inputs included in the analysis. In this case, we would probably deal with somewhere between 7 and 15 inputs and outputs, which raises the need for data from between 25 and 50 airports. As evident from Section 1.3.2, data from this number of airports is available.

Despite its few weaknesses, most of which can be corrected for, e.g. by applying the bootstrapping method, DEA is a useful for investigating the efficiency of government service providers such as Avinor. It is the potential benefits of DEA as compared to other approaches that must be recognised and explored to increase the understanding the performance of Avinor and, if needed, possible ways of improving that performance.

1.3 Data availability

1.3.1 The PPM approach

Most airport operators normally publish detailed traffic statistics and information can be obtained from annual financial reports on total costs, operating costs, labour costs and depreciation. Also included in these annual financial reports is data on staff employed by the airport authority. With respect to Avinor, they publish an annual financial report which provides data which is aggregated across all airports. With respect to the availability of individual financial information for each airport, we have been assured by Avinor that it will be possible to obtain the necessary information from individual airports should it be decided that there will be a comparison of individual airports.

Data requirements are more challenging when benchmarking between airports that are managed within large national networks. Apart from traffic data, which is usually available at an individual airport level, financial and employee data disaggregated by individual airport may be more difficult to obtain. Some operators, such as Swedavia (Luftfartsvärket (LFV) until 1st April 2010) in Sweden, publish some information on their individual airports.

Data on staffing, capital expenditure, revenue and profit is clearly available. This would imply that Swedavia has an internal accounting system that has established profit centres at each airport where more detailed cost information could be obtained. Availability of this data and more detail on the degree of out-sourcing and other pertinent items of information would only be forthcoming with the cooperation of Swedavia.

Finavia, like both Avinor and Swedavia is a state-owned enterprise that operates a network of airports. Traffic information is available for their individual airports. They can provide 10 years of financial information and human resources data for each of their 25 airports. Operational data for each of Finavia's airports (e.g. on terminal space, runways, staff) is available.

Because the UK airport industry is largely privatised and deregulated, airports are owned separately and both detailed financial and traffic statistics are readily available for most airports.

A challenge in terms of data is to obtain individual cost centre data for each airport for standardisation and normalisation purposes. For example, one unknown/risk factor would be the degree to which it would be possible to obtain information on the revenues, costs, and employees associated with a small Swedish airport’s ground handling activities for the purposes of normalisation.

A list of performance indicators, the data needed to calculate these indicators and their respective sources are given in Table 4.7, Section 4.2.4. For the majority of performance indicators, one would expect most data sources to be accessible, primarily through various published sources either through the operators themselves or through trade associations such as ACI. At an individual airport level, traffic statistics are usually very accessible either through ACI publications (World Air Traffic Report) which have consistent reporting formats, through national civil aviation regulators or from individual airport traffic reports which are normally available for download on respective websites. However, the availability of financial data, especially on cost depends on whether the airport is managed by a national system operator such as Avinor or whether the airport it is managed by a single operator. For some national operators, financial data availability for individual airports is good. For others, like Aena, such availability might be difficult. For the multiple airport system operators it is unusual for individual airport financial data to be published and therefore approaches to individual airport would be necessary and success therefore entirely dependent on good-will. The same is true with regard to physical data such as number of gates and total terminal space. In this case, there is no single published source and a researcher would therefore have to approach airports individually or obtain such information from websites.

1.3.2 The more sophisticated approach

Below, the data availability for a two-stage DEA approach is listed. Table 4.7 does also provide some information on this issue. We have focused on a comparison between Avinor and operators in countries with a fairly similar governance structure for airport operations. In terms of governance structures; Avinor, Swedavia, Finavia and Isavia are very similar. They are government-owned airport operating companies (and limited companies). They tend to have an overall corporate structure and centralised administration but with divisions that are responsible for groups of airports. Their largest airport (the capital city airport) is typically owned and operated as a subsidiary of the airport operator. HIAL is operated in a slightly different way.

Norway: Avinor have good data on all relevant input and output factors for a DEA study. Some additional data would have to be collected for the two-stage regression analysis (like e.g. weather conditions and outsourcing of operations), but this data is easy to obtain. In addition to Avinor’s airports, operational data (for a DEA technical efficiency study) from Sandefjord/Torp (TRF) will be available. Data from the newest private airport, Moss/Rygge (RYG) are not available. The airport has been operating only since 2008, which makes it less suitable for comparison.

Sweden. Traffic data is available from 1997-2009 for 41 airports (passengers, freight and mail, and aircraft movements). 14 of the airports are operated by Swedavia and financial information is available from 2004-2009 for each of those airports (e.g. capital expenditure, labour cost, turnover, operating result). Operational data is also available (e.g. on terminal space, runways, staff). Staff numbers may have to be converted to full time equivalents. For non-Swedavia airports, contact is established and data can be provided upon request.

Finland. Traffic data from 1998-2009 is available for 27 airports. 25 airports are operated by Finavia. Financial accounts for Finavia airports are consolidated in their annual report. They can provide 10 years of financial information and human resources data for each of their 25 airports. Operational data for each of Finavia's airports (e.g. on terminal space, runways, staff) is available.

Iceland. All of the airports are operated by Isavia (14 airports). Given the timing of this data check, the current ash-situation means that it is hard to get non-urgent phone calls answered for the time being. Information is not easily available from their website. Some operational data is on the AIP's which we can access (e.g. number and size of runways). We believe that data from these airports will be available.

Scotland: For the Highlands and Islands group of airports, there is access to annual accounts from 2003/04 – 2008/09. Although their annual accounts are aggregated for the group, they report operating costs and revenue for the following airports individually: Barra, Benbecula, Campbeltown, Dundee Airport Ltd, Inverness, Islay, Kirkwall, Stornoway, Sumburgh, Tiree, Wick. It should also be possible to get suitable operational data.

AIP's are freely available for all airports in Sweden, Finland and Iceland. They provide the number and size and runways. The UK CAA published AIP's for the Scottish airports so those are also available.

An operational comparison of around 140 airports in Norway, Scotland, Sweden, Finland and Iceland is possible if based on simple inputs (labour, number and size of runways, number and size of terminals, airport area) and outputs (passengers, cargo and aircraft movements). A financial comparison is more difficult although comparing airports of Avinor, Swedavia, Finavia and HIAL (around 90 airports in total) should be possible.

Aena (Spain) and ANA (Portugal) are two additional options as they are large airport operators like Avinor, Finavia, Swedavia, Iceavia and HIAL. Operational data is available for Aena and ANA, but financial data for Aena is probably not accessible. Besides, focusing on airports belonging to the large airport groups in Northern Europe may provide a sufficient basis for comparisons.

1.4 Recommendations for a main study

Ideally, one could want to address Avinor's efficiency for a decomposed structure into profit centres, based on a breakdown of the chart in Figure 1.1 above. We would however recommend moving forward with a study that takes the airports as the units of analysis. A further breakdown would probably leave a significant amount of uncertainty with respect to both data availability and comparison possibilities. Overhead costs could be allocated to each airport in line with what is described in Section 4.2.3.1.

A study could be done in three ways, and these ways are complementary in nature:

4. An internal benchmarking study of Avinor's airports, where one could apply a PPM study and/or a 2-stage DEA study. Data for both methods should be readily available from Avinor. Such a study would circumvent some of the comparability issues, but will still probably be able to identify differences between "best practice airports" and the others within Avinor's system. The limitations would be that all these airports are operated a under common governance regime, which could veil potential efficiency implications of different national governance systems. For a DEA technical efficiency study, data from one Norwegian airport outside Avinor's system (Sandefjord/Torp, TRF) will be available.
5. A PPM comparison between a selection of Avinor's airports and a number of comparable international airports, based on the methodology (PPM) in Cranfield (2006). Comparison should be made with care, with respect to:

    - Size
    - Traffic characteristics / mix
    - Role of airport within air transport system (hub or regional airport)

- o Economic conditions / level of development
- o Regulatory / ownership structure
- o Degree of out-sourcing

6. A 2-stage DEA analysis on a larger set of airports. In our opinion, we have reasons to state that data from around 150 airports in Northern Europe would be available, at least for a DEA on technical efficiency. It is likely that financial data for a large subset of airports (around 90) would be available, to assess allocative efficiency as well. We would recommend that: (1) DEA be conducted in two stages, where in the second stage the DEA efficiency scores are regressed on external factors such as ownership, regulation, weather conditions etc., to infer how these factors influence efficiency and, (2) DEA be conducted together with bootstrapping to certain confidence intervals for the efficiency scores derived and, (3) DEA's extension to the Malmquist Productivity Index (MPI) should be used to study the developments in efficiency over time.

   We would like to recommend the third approach, namely a 2-stage DEA analysis on a larger set of airports, however with the option to limit the study to the first and second approach. The recommendation is made from the fact that data availability seems to allow this more sophisticated approach. The recommendation is strengthened as compared with the commentary version of the report because Finavia has confirmed appropriate data availability for individual airports.

2 INTRODUCTION

2.1 Objectives and limitations

According to the tender announcement (TA), the purpose of this project is twofold:

- It should give an overview and an assessment of all studies that compare Avinor's cost efficiency with other providers of comparable services.
- The study should give directions for further research, including assessment of data availability and methodological challenges.

We have interpreted this purpose to include all sides of Avinor's activity, including its subsidiary OSL. We have considered how far we can get when comparing with other Norwegian service providers (like the airports TRF and RYG) and with foreign providers of comparable services. We have also considered the possibilities of doing an internal benchmarking, where different units within the same company or sector are compared. This is done e.g. in the Norwegian road ferry sector (Odeck og Bråthen 2009), where the potential for increased efficiency is estimated, given that all ferry links apply "best practice" operations. In this work, the factors affecting the differences in efficiency, were also described and assessed.

According to the TA, an analysis of cost efficiency is demanded. We have also considered the possibility of doing a technical efficiency study, which can also contribute to an understanding of Avinor's efficiency as compared with other operators. The advantage of this method is that it is less data demanding in terms of financial information, which is often considered as sensitive information.

The pilot study assesses methods and available data with respect to whether it is possible to get a picture of how Avinor's efficiency has developed over time, as compared to its competitors.

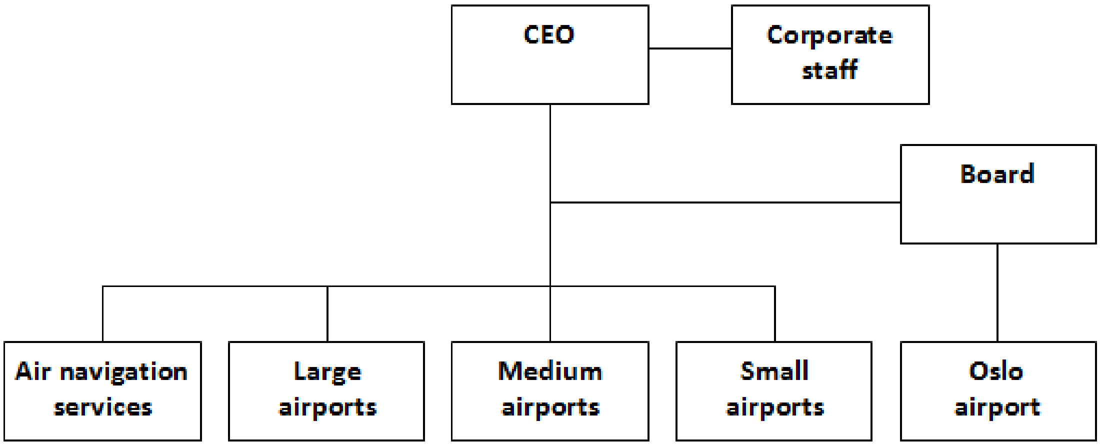
2.2 Main content of the prestudy

Avinor's infrastructure services are mainly connected to:

- Airport operations, including the provision of space for other commercial (non-airside) activities.
- Investments in airport infrastructure.
- Air Traffic Control.

We have used Avinor's organization plan as the point of departure for assessing the efficiency issues for the various activities. The organization map is shown below.

Figure 2.1: The structure of Avinor



(Source: www.avinor.no, with our translation)

This structure is used as a base for the search for possible methods and data for a prospective main research project. Many operational units are placed underneath this superstructure, like air navigation services, ATC, and all the airports. There are also different profit centres underneath these sub units. However, there will be a question of how far we can go with this breakdown with respect to an international comparison. Doing the analysis on the right aggregation level would influence the possibilities of obtaining data to do a robust comparison and to identify the important cost drivers. We have considered it as important to identify the possibilities of establishing a robust foundation for using comparable data. We have also discussed the organizational and political framework under which the provision of air transport services are given.

Parts of Avinor's activities are namely done under various kinds of political objectives, which may affect the efficiency of Avinor's operations. This factor may be of particular interest when assessing the efficiency of the smaller airports. One might also have various local ways of organizing some of the operations. Winter-time maintenance and/or fire protection services can be given in cooperation with the local authorities. This is a kind of outsourcing, and outsourcing may also be present in other parts of

Avinor's system. In addition, some of the airports will have special attention towards non-airside activities, which also have to be taken into account.

We have surveyed what data can be obtained from international studies, e.g. from ATRS (2009) and Cranfield (2006), and directly from other sources.

We have considered if the data will make more formal methods like Data Envelopment Analysis (DEA, non-parametric) and Stochastic Frontier Analysis (SFA, parametric) as suitable methods, supplied with conditional regression analyses to map the causes of differences in cost efficiency. DEA and SFA are two competing methods that can be applied on the same data. These methods are frequently used in international research, also for air transport (see e.g. Oum et al., 2008). A thorough assessment of data quality and comparability is of course of paramount importance.

2.3 Content of the reporting

The reporting will be in accordance with the two main points listed at the beginning of the introduction. The main part of the reporting will be related to the second point, namely the assessment of data availability and choice of relevant methods. A discussion of the adequate aggregation level that can allow for a comparison between service providers will also be given.

Mapping of data is necessary to decide upon whether a main study will significantly improve the understanding of Avinor's performance. This mapping will be given in terms of relevant variables, in what scope (time period and for which service providers), on what conditions, and with respect to what kind of analyses the data can support – including an assessment of which adequate methods can be used.

The report will give specific recommendations as to how a main project should be designed, and with a rather thorough description of data availability.

3 AVINOR'S REGULATORY AND INSTITUTIONAL FRAMEWORK

3.1 General

Avinor is responsible for planning, developing and operating the Norwegian airport network. Avinor operates 46 airports in Norway, twelve of these in cooperation with the Royal Norwegian Air Force. Operations also include air traffic control towers, control centres and technical infrastructure for aircraft navigation.

Avinor was founded on 1 January 2003, by the conversion of the Norwegian Civil Aviation Administration known as Luftfartsverket into a state-owned limited liability company. The Norwegian state, via the Norwegian Ministry of Transport and Communications controls 100 percent of the share capital. In addition to the 46 airports, Avinor also operates three Area Control Centers: Bodø Air Traffic Control Center, Stavanger Air Traffic Control Center and Oslo ATCC.

Like most other airport operators, Avinor is self-financed and hence receives no state subsidies apart from a smaller amount to the airports in remote regions. Revenues are derived from aeronautical charges paid by airlines and commercial activities at the airports. The air traffic control service operates at cost. Four of 46 airports operate with a profit (Oslo, Stavanger, Bergen and Trondheim) and subsidize the remaining airports. Security expenses are covered by the security fee.

According to its bylaws, Avinor produces a strategy plan for its activities every year. Every two years this plan forms the basis for a Goverment White Paper or report to the Norwegian parliament (Storting), written under the auspices of the Ministry for Transport and Communication. The most recent report was sanctioned by the Storting in 2009. This document (the §10-plan) is in essence Avinor's operational plan, describing the current situation and constraints, past performance, future challenges and planned investments.

3.2 Corporate structure

Avinor is organized into four divisions, with a corporate staff serving the head office, located in Oslo. The corporate staff consists of the CEO, CFO, HR and organization director, strategy director, safety and security director and communications director. Division directors head the Air Navigation Services division and the Large airports division, Medium airports division and Small airports division. Oslo airport (Oslo

Lufthavn AS) is a wholly-owned subsidiary and has its own managing director and board.

3.2.1 Air Navigation Services (ANS)

The Air Navigation Services Division is organized into two business areas. Business Area Air Traffic Management is responsible for providing air traffic services within Norwegian airspace, including designated parts of the North Atlantic airspace. In addition, air traffic services are provided at 21 controlled aerodromes, including Oslo Airport.

The Business Area is divided into 5 Business Units, which also includes the AIM/AIS services and the meteorological services. Air traffic services are provided to both civilian and military operators.

Business Area ATM/CNS Systems is responsible for installation and management of ATM/CNS equipment to the Business Area Air Traffic Management and to 52 aerodromes in Norway. The Business Area ATM/CNS Systems is divided into three Business Units, which are ATM/CNS Operations, ATM/CNS System Projects, and ATM/CNS Systems Development & Support.

3.2.2 Airports

The airports are grouped into three sets: Large; Medium and Small. Oslo airport (OSL) is a separate subsidiary, see below.

Table 3.1: Larger airports

Airport	Passengers 2009
Bergen Airport, Flesland	4 480 876
Trondheim Airport, Værnes	3 423 927
Stavanger Airport, Sola	3 417 400
Tromsø Airport	1 556 390
Bodø Airport	1 433 256

Table 3.2: Medium-sized airports

Airport	Passengers 2009
Kristiansand Airport, Kjevik	844 363
Ålesund Airport, Vigra	749 152
Haugesund Airport, Karmøy	532 352
Harstad/Narvik Airport, Evenes	498 923
Molde Airport, Årø	348 424
Alta Airport	318 173
Kirkenes Airport, Høybuktmoen	277 244
Kristiansund Airport, Kvernberget	273 083
Bardufoss Airport	175 408
Svalbard Airport, Longyear	129 336
Lakselv Airport, Banak	50 575

Smaller airports

The Regional airports division overseeing 29 airports is divided into four districts headed by district directors. With one exception, these regional airports are STOL-airports, and the route network is almost exclusively served by PSO contracts. Passengers for 2009 ranged between 6 000 and 100 000 approximately. With full liberalization of the domestic air transport market, the main part of the STOL network was subsequently declared PSO-routes and offered by public tender.

3.2.3 Subsidiaries

3.2.3.1 Oslo Lufthavn AS (OSL)

OSL is a wholly-owned subsidiary of Avinor. OSL's task is to operate the main airport at Gardermoen. OSL has been named Europe's most punctual airport three times. The company has approx. 600 employees.

3.2.3.2 Avinors Parkeringsanlegg AS

Avinors Parkeringsanlegg's task is to facilitate, finance and own parking facilities adjacent to and connected to Avinor's airports. The company currently owns the parking facility at Stavanger Airport Sola, Bergen Airport Flesland and Trondheim Airport Værnes. The company is building a new parking surface at Tromsø Airport Langnes. The company has no employees, and Avinor handles the company's day-to-day management.

3.2.3.3 Flesland Eiendom AS

Flesland Eiendom AS is the owner of the airport hotel Clarion Hotel Bergen Airport. The hotel is operated by Choice.

3.2.3.4 Værnes Eiendom AS

Værnes Eiendom AS has been established in connection with the construction of a hotel at Værnes.

3.3 Some factors affecting Avinor's performance

Avinor's future development is influenced by the general economic development, the current market situation and the limitations set forth by the Ministry of Transport and Communication (MTC), acting as owner on behalf of the state.

With 46 airports spread all over Norway, Avinor's airports channel close to 96% of Norwegian air traffic, whereby Avinor effectively can act as a monopolist. There are six airports in Norway not owned by Avinor. Two of these are large airports, Sandefjord/Torp (TRF) and Moss/Rygge (RYG), are close to Oslo and partially compete for the same passengers, while the four others are smaller airports.

Acting as the sole owner of Avinor, MTC defines Avinor's mission, including Avinor's responsibility for adding to the social welfare of the country by upholding an airport infrastructure where parts of the network is dependent on subsidies.

MTC may impose tasks on Avinor or set forth certain requirements to its operations (like having specific opening hours and airports in sparsely populated areas), which may be in conflict with Avinor's financial responsibility.

Some of these task are:

Planning: Avinor is responsible for research and review of aviation issues, particularly related to the National Transport Plan, produced every four years and elaborates on how the Government intends to prioritise resources within the transport sector over the next ten years.

Statistics: Avinor is responsible for providing detailed traffic statistics on airport usage for all Norwegian airports.

Emergency Preparedness: Avinor is responsible for keeping the airports open for the helicopters and planes used by the emergency services, both within and outside of the regular opening hours of the airports.

Universal access: Avinor is responsible for providing airport access to people with disabilities in accordance with Norwegian Law, meaning that airports are to be universally accessible by all members of the general public, regardless of disabilities.

Public transport: Avinor is be an initiating and driving force in ensuring that all airports are accessible by various modes of public transport wherever possible. However, the ground transportation and its financing are the responsibility of others.

3.4 The current political framework

The "Soria Moria" declaration, which is a common political platform for the current government coalition, contains a number of goals for aviation in Norway:

- All airports are an integral part of the Norwegian infrastructure and there shall be an airport network that provides adequate access to air transport to all areas of Norway.
- Today's airport structure shall be maintained and no airports shall be closed, unless there is a local desire to do so, and only after there has been a thorough review process with participation of all stakeholders
- Safety and regularity at STOL airports shall be ensured by establishing better airport approach systems and equipment.

MTC acts as regulatory authority as to the fees that Avinor can level on the use of its services. Consequently, it is MTC which determines Avinor's income potential. One option is to set a level and then increase the fees annually according to the consumer price index, another option is a yearly re-evaluation based on suggested future investments and the need for capital. MTC expects Avinor to pay 50% dividend over the next 3-5 years.

3.4.1 National Transport Plan NTP 2010-2019 (NTP)

The National Transport Plan NTP is produced every four years and it states how the Government intends to prioritise resources within the transport sector over the next ten years. The National Transport Plan discusses current policy issues, and it aims to provide a basis for decision-making. Investment schemes are implemented within eight defined national and transport corridors. It should be noted that this is a tentative scheme, where the prioritization of projects and the actual investment decision, as well as the allocation of funds and takes place in the parliamentary sessions.

In NTP 2010-2019, Avinor proposed that the STOL airports should be funded as PSO as well, and not by cross-subsidization from profitable airports. Cross-subsidization limits the annual dividend and puts constraints on Avinors future investment possibilites. Avinor operates Oslo airport in completion with the aforementioned Torp and Rygge airports, which are allowed to determine their own fee structure, while Avinor must abide by government-regulated fees. Hence, the three larger airports in the Oslo fjord area are competing under different terms and conditions.

For each of the eight transport corridors, NTP 2010-2019 identifies necessary investments at the associated airports in a total of around 25 BNOK, in many cases to make upgrades in connection with BSL E 3-2 requirements.

3.5 Summary of Avinor's regulatory and political framework

In connection with the main study, it will be important to identify the differences in the organisational structure and policy framework that can affect Avinor's performance when measured against international airports. It may be that e.g. the responsibility for planning of airport operations could be either centralised or allocated to each airport. It could also be that some airport's opening hours (affecting the number of full-time employment equivalents, FTE) are determined from external factors, like e.g. the need for serving air ambulances. Such external factors should be identified and included in the analysis, e.g. by means of a 2-stage DEA approach as described below.

4 RESEARCH METHODS

4.1 General

In this section, we will discuss the various research methods that can be applied in a main project. These are:

- Partial Productivity Method (PPM)
- Data Envelopment Analysis (DEA) with 2nd stage regression analysis
- Stochastic Frontier Analysis (SFA)

4.2 Partial Productivity Measures

4.2.1 Theory

Applying partial indicators of performance is the traditional and most commonly used method to compare airports. This approach was initially pioneered by various researches conducted by the Transport Studies Unit at the University of Westminster and the Department of Air Transport at Cranfield University.

Typically these studies focus on the following dimensions of airport performance:

- Cost efficiency
- Productivity
- Revenue generating capability
- Profitability

For each of these dimensions, measures have been developed which relate in some way the airport's inputs and outputs. The major inputs in an airport system are: labour and capital. Depending on the performance measure used, the inputs are measured in either physical or financial terms. For example, labour can be expressed in terms of number of employees or in terms of total labour costs incurred by the airport. Capital is usually measured in physical terms and can be represented by for example, the capacity of the runways or the amount of terminal space allocated to retail activities.

As far as output is concerned various measures can be used. Traffic represents the key output of an airport and there are typically three dimensions; passengers, freight or aircraft movements. For the majority of civil airports, the most important output is passenger traffic. However, some airports have substantial freight activity. The challenge for researchers in the partial performance field has been to devise robust and reliable measures of output that cover the different types of traffic. The Work Load Unit (WLU) was devised to solve this problem as it essentially combines passenger and freight volume into one aggregate measure of airport output. This is achieved by converting freight volume into passenger numbers by assuming that 100 kg of freight is equivalent to 1 passenger. This conversion is shown in the formula below:

$$WLU_{it} = P_{it} + \left[\frac{F_{it}}{100}\right] \quad \text{(Equation 4.1)}$$

Where WLU_{it} represents Work Load Units generated by airport *i* in time period *t*, p_{it} represents passengers and F_{it} is freight in kilograms. It should be noted that WLU is an arbitrary measure of output since an airport will not necessarily employ the same amount of resources in handling both types of traffic. Indeed, in the majority of cases, cargo airlines through handling, processing and storage will be responsible for freight activities at an airport. In terms of passenger handling, the role of the airport is much more significant. One solution to this problem could be to attach weights to the passenger and freight components of output reflecting the relative magnitude of labour inputs into handling both types of traffic. However, this then raises a further complication, especially in the case of small regional airports where resource inputs (i.e labour) can be used to support both passenger and freight activities.

Research by Vallint (1998) attempted to explore the potential for alternative measures of airport output and subsequently developed the Airport Throughput Unit (ATU) which incorporates the WLU and aircraft movements. This is shown in the formula below:

$$ATU_{it} = \left[\frac{WLU^2{}_{it}}{ATM_{it}}\right] \quad \text{(Equation 4.2)}$$

Where ATU_{it} represents Work Load Units generated by airport *i* in time period *t* and ATM represents air transport movements. The ATU method is rarely used suffering from the weakness that it actually represents a measure of productivity rather than output since a high value would indicate that the airport facilities are being more efficiently utilised through the use of larger aircraft. In their benchmarking study, Jacobs Consultancy (2007) uses their own alternative ATU (Airport Throughput Unit). This is shown in the following formula:

$$ATU_{it} = P_{ij} + [10(F_{it})] + 100(ATM_{it}) \quad \text{(Equation 4.3)}$$

Where ATM_{it} represents the air transport movements handled by airport *i* in time period *t*. F_{it} is expressed in tonnes rather than kilograms. The value of 100 appears to have been based on the assumption that, on the basis of previous studies, handling one ATM requires approximately the same amount of effort as handling 100 WLUs.

Since the proposed Avinor study is likely to focus on cost efficiency and productivity rather than on revenue generating capability and profitability, the following assessment will be made of the use of partial cost efficiency and productivity measures.

Cost efficiency is usually measured by relating output (WLU or ATU) to a financial measure of cost. Typically most previous studies have used total operating cost per WLU as a measure of cost efficiency. Total operating cost will include, labour, depreciation, administration, materials, supplies, service procured, energy etc) essentially all the costs associated with running the airport. Depreciation is sometimes excluded because as it is an accounting cost designed to represent physical deterioration of an airport's fixed assets and it does not relate to the day-to-day operations of an airport as the other operating costs do. It is also possible to produce more disaggregated measures of cost efficiency by measuring the unit costs associated with separate expenditure components. As labour usually represents an airport's most significant item of operating expenditure, many studies have used the labour costs per WLU measure to ascertain the cost efficiency of employee resources.

In terms of measuring an airport's productivity, traditionally average WLU per employee has been used to measure output per unit of labour input while capital productivity has been measured by calculating the average total assets per employee.

A summary of performance indicators more commonly used to assess cost and productivity are shown in the table below:

Table 4.1: Performance indicators

Cost	**Productivity**
Operating costs (net of depreciation) per WLU / ATU	WLU per employee
Operating costs (inc of depreciation) per WLU / ATU	Revenues per employee
Labour costs per WLU	Total assets per employee

4.2.2 Interpreting results

One of the most important advantages to using these types of measures is that they are intuitively very simple to compute and understand. That explains their popularity especially amongst practitioners i.e airports themselves, banks and management consultants. They can provide some very useful information on the relative performance between airports.

However, there are a number of challenges in interpreting the results when using these simple indicators of cost efficiency and productivity. This is largely related to contexts where one is comparing the performance of different airports.

One of the most challenging aspects of undertaking these partial performance comparisons is that marked differences between airports will exist in the way their facilities are managed. For example, there will be substantial variations in the degree of outsourcing between airports. This will have a significant effect on the labour costs efficiency and productivity comparisons since airports that manage a high proportion of their facilities and services in-house will inevitably be perceived as having lower labour cost efficiency and productivity compared to an airport that has out-sourced a greater proportion of its activities. Most airport authorities will be responsible for the overall management of the terminal and airside facilities (taxiway, runway etc). However, within these areas there are likely to be substantial differences in the degree of outsourcing. For example, some airports will out-source passenger security and others will keep in-house. Also, at some airports, the airport authority will be responsible for local air traffic control whereas at others, this service is provided by the national air navigation service provider. Even in the area of retail activities it is possible to find instances where there is direct airport involvement through subsidiary companies rather than the conventional use of concession contracts. These inconsistencies and variations are more likely to occur in situations where an international comparison is being undertaken. This is due to the evolution of distinct and sometimes very nuanced local practices and approaches to managing airports. This is less of a problem when comparing airports that are managed by one national operator (e.g. Avinor) since it would be expected that there would be commonalities across the airport system in terms of the degree of out-sourcing. However, one would probably expect there to be significant differences, due to the economies and practicalities of outsourcing, between very large and very small airports within one network.

One solution to this problem is to standardise the data so that each airport is assumed to be undertaking a uniform set of activities. In previous studies by University of Westminster, Cranfield University and more recently by the Jacobs Consultancy, adjustments have been made on this standardized basis, where it is normally assumed that non-airport core services such as ATC, ground handling and duty-free are out-sourced to third party suppliers. If there are airports that provide these services in-house the revenues, costs and employee numbers of these activities are isolated and excluded. In the case of duty-free, as it would be assumed that a standard concession contract would replace the in-house operation, for example, the costs and employees would be excluded and 30% of the sales revenues from the duty-free operation would be taken as notional concession fee income.

Another issue is where there are networks and groups of airports that are managed by national authorities. It would be necessary to ensure that whatever data is provided at a disaggregate level, there would need to be some accounting for head office / central administration costs that would need to be apportioned to each individual airport for comparison purposes.

Having standardised the data it would then be possible to undertake a more meaningful comparison. However, the process of standardisation essentially entails a departure from reality. Indeed, what the comparison then ignores is the decision to out-source which is itself an important management decision which will affect performance relative to its peers. The argument against standardisation is that it is perhaps more effective to benchmark the airports as they are and then to explain the relative performance within the context of variation in degrees of out-sourcing.

The effect of exogenous variables on the performance measures also needs to be appreciated especially so in cases where there is an international comparison. For example, the effect of economic regulation and operational restrictions will affect performance comparisons. Some airports in one jurisdiction may be subject to a particularly heavy-handed form of price control economic regulation which will constrain the yield from aeronautical revenue while the presence of night curfews will limit the degree to which some airports may be able generate freight business.

International comparisons will also be affected by the use of different common currencies. Previous studies have used the US Dollar. The use of official exchange rates will ignore the relative difference in price levels between countries. This is a particular problem if contrasting airports that are located in regions that have vastly different costs of living. One solution to this problem is to use the Purchasing Power Parity exchange rate which adjusts exchange rates by taking into account relative price levels between countries. Alternatively, the special drawing right (SDR) has been used in some previous studies. The SDR is a basket of four currencies (US Dollar, Euro, Sterling and Japanese Yen) which are weighted according to the relative importance of each currency in international trade. The SDR is able to remove the effect of significant currency fluctuation on performance indicators that can happen when using official exchange rates.

Many of the risks and pitfalls that have been highlighted can be mitigated to some extent by the choice of airports used for any study. An internal comparison of airports within one national jurisdiction would be relatively straight forward and would be free of most of the challenges already mentioned. If undertaking an international comparison, in terms of comparability there would need to be a very careful selection of airports. Ideally airports that are similar in the following ways should be chosen:

- Size
- Traffic characteristics / mix
- Role of airport within air transport system (hub or regional airport)
- Economic conditions / level of development

- Regulatory / ownership structure
- Degree of out-sourcing

4.2.3 Previous studies using PPM

4.2.3.1 Avinor 2005

The Department of Air Transport at Cranfield University were contracted by Avinor in 2005 to undertake two studies. The first study contrasted the air transport system in Norway with other countries. The second study was designed to compare the economic efficiency of Avinor with other comparable European airport operators and systems. The study focused on five key areas:

- Airport economic performance
- Air navigation system economic performance
- Airport user charges
- Degree of internal airport cross-subsidisation
- State aid to airports and airlines

The following airport organisations and systems were selected for comparison:

- Avinor
- LFV (Sweden)
- Aena (Spain)
- ANA (Portugal)
- Finavia (Finland)
- CAA Iceland
- Scottish Airport System

Five out of the six systems were selected on the basis that like Avinor, the airport networks were managed by single state-owned enterprises. The exception was Scotland which was included to evaluate how Avinor compared to a system that was largely fragmented and privately-owned.

The following measures were selected for the airport economic performance comparison:

- average operating cost per passenger
- average labour cost per passenger
- average aeronautical revenue per passenger
- average non-aeronautical revenue per passenger
- average operating profit per passenger
- average capital expenditure (past 5 years) per passenger
- operating margin

- average passengers per employee
- average revenue per employee
- average labour cost per employee

The study received data from a combination of sources including; various annual financial reports, Eurocontrol performance report and an individual questionnaire which was sent to selected contacts in Swedavia, Finavia and the Icelandic CAA.

In order to maintain consistency between all data sets, data for each airport system also included revenues, costs and employee numbers associated with terminal navigation services. Where possible data relating to the direct provision of ground handling services was also removed from the analysis and where the organisation operated both airport and ANS, an allocation of central administration overhead costs was made to the airport data.

Table 4.2: Airport services provision

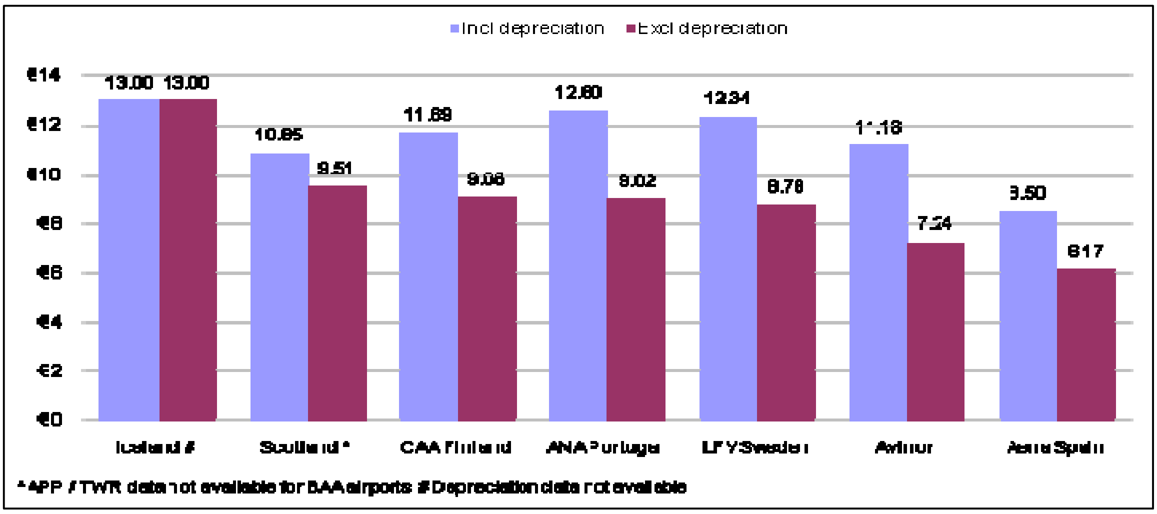
	Passenger Security				Ground Handling		Fire & Rescue		Retail activities	
	DP	OS	SC	SF	DP	A/GH	DP	Other	DP	CONC
Avinor		✓				✓	✓			✓
Aena (Spain)		✓				✓	✓			✓
ANA (Portugal)		✓	✓		✓[1]	✓	✓			✓
Iceland System	✓					✓	✓	✓	✓	
CAA Finland	✓				✓[1]	✓	✓			✓
Swedavia (Sweden)	✓				✓[1]	✓	✓			✓
Scottish system	✓	✓			✓	✓	✓		✓	✓

[1] Ground handling services provided by a subsidiary company

Definition of Codes: A/GH = Airline and/or ground handling companies, DP = Direct provision by the airport operator, OS = out-sourced to a contractor, SC = Service provided by the state and charged to the airport, SF = Service provided by the state and not charged to the airport, CONC = Service provided by a company that has a concession.

Avinor operates a large number of very small airports in remote regions where there are high fixed costs and low volumes of traffic. Therefore, system-wide unit operating costs would be expected to be higher than most of the other airport systems included in the survey. Figure 4.1 shows operating cost per passenger with and without depreciation. Avinor appears to be very cost competitive when removing the effects of depreciation. The relatively new Oslo airport may be the cause of a high level of depreciation with regard to Avinor. The study found, in this case Avinor to be quite cost-competitive relative to its European peers.

Figure 4.1: 2003 Operating cost per passenger by airport ($ purchasing power parity exchange rates)



Source: *2005 Avinor Report*

Table 4.3 below provides a comparison of operating costs per passenger both with and without depreciation with the indices expressed in US dollar purchasing power exchange rates. It provides a summary of Avinor's performance across each indicator with ranking relative to its peers. Focusing on cost competitiveness and productivity, Avinor performs rather well compared to its peers but performance is poorer in other areas.

Table 4.3: Summary of Avinor performance analysis

Performance indicators	Avinor's performance in the group	Avinor's Rank (out of 7)	Top Performer	Poorest Performer
Aero revenue per pax	Poor	6	ANA	Aena
Non-aero revenue per pax	Poor	6	Iceland	Aena
Opertaing revenue per pax	Poor	6	ANA	Aena
Labour cost per pax	Good	2	Aena	ANA
Average lab cost per employee	Good	3	CAA Finland	Aena
Operating cost per pax (ex depreciation)	Good	2	Aena	Iceland
Operating profit per pax (ex depreciation)	Good	3	ANA	Aena
Operating margin (ex depreciation)	Good	2	ANA	Iceland
Capital expenditure per pax	Poor	6	ANA	Scotland
Pax per employee	Good	3	Aena	CAA Finland
Revenue per employee	Average	4	Aena	CAA Finland

Care needs to be taken in terms of interpreting Avinor's performance at such a level of aggregation. Aena manages a similar number of airports to Avinor but the traffic volumes are much greater and there is a larger number of viable units within their airport system. Swedavia operates a smaller number of airports since most of the small Swedish regional airports are managed by local municipalities. Due to time constraints and resources full and comprehensive normalisation of the data was not possible. The study was useful for providing an overall picture of Avinor's position. However, if time and resources would have allowed, a more disaggregated analysis would perhaps had been more useful and informative.

4.2.3.2 Jacobs Airport Performance Indicators 2007

Jacobs Consultancy produce an annual airport performance benchmarking report covering a sample of 50 key airport operators spanning the continents of North America, Europe, Africa, Asia and Australasia. Their analysis covers the use and application of standard and widely accepted partial measures such as total cost per passenger, operating cost per passenger and passengers per employee. Furthermore, balance sheet financial ratios are also used such as Return on Capital Employed (ROCE). In total around 40 measures are used. What is different from previous studies is that for some of the measures, use is made of the Airport Throughput Unit to represent output as described in Equation 4.3, rather than the more commonly adopted Work Load Unit. All financial data was converted from national currency units to Special Drawing Rights (detailed in Section 4.2).

The potential distorting effects of differences in degree of out-sourcing were addressed through a normalisation/standardisation of the data set very similar to than described in section 4.2. In terms of the range of airport operators selected, the sample included a mix of publically and privately-owned airport operators. The comparison is complicated by the presence of single airport operators such as Oslo, Geneva and Sydney being contrasted with multiple airport operators such as the Malaysian Airports Group, Airports of Thailand and BAA. Avinor is not included as a group but Norway is represented by the subsidiary company that manages Oslo Airport, Gardermoen.

Figure 4.2 below is based on data obtained from the study and contrasts total costs per passenger across a sample of European airports. It is difficult to draw meaningful analysis from this table because there is a mixture of very disparate types of airport operators. Intuitively, due to the presence of economies of scale, one would expect larger airports to have lower unit costs. Two of Europe's busiest airports, London Heathrow and Aeroports de Paris, appear to have very high total cost per passenger compared to the others. In the former case this is probably due to the effects of Terminal 5 construction expenditure and interest payments on the airport's total costs. The same airports in the same order are also included in Figure 4.3 but this time using 1000 ATU as the measure of output. The ranking is little different. The exceptions being both London airports where the average number of passengers per air transport movement is high and the Finnish and Swedish airport operators where the application of this measure makes them appear more cost competitive due mainly to the fact that their lower costs are spread over a roughly equivalent volume of air transport movements compared to the larger airports.

Figure 4.4 compares ATUs per employee for all airports in the sample. In this instance, oslo appears as the most efficient European airport in terms of labour productivity. One should also observe that the most productive airports are generally Australian or American whilst some major European airport operators and some of the multiple airport groups appear as the least efficient.

Figure 4.2: Total costs (2007) per passenger in SDR: sample of European airport operators

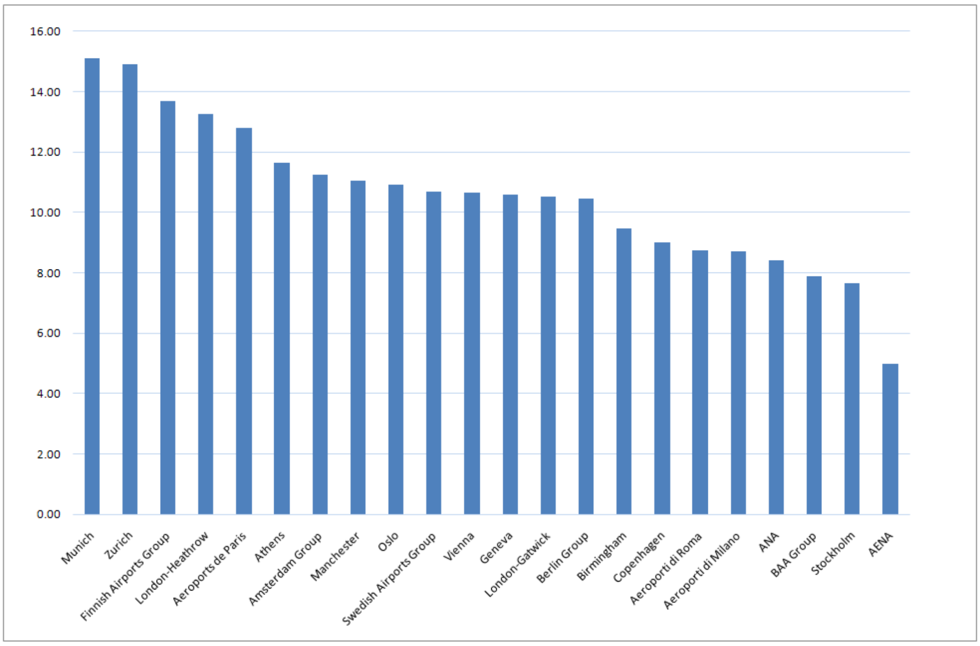


Figure 4.3: Total costs per 1000 ATU (2007) in SDR: sample of European airport operators

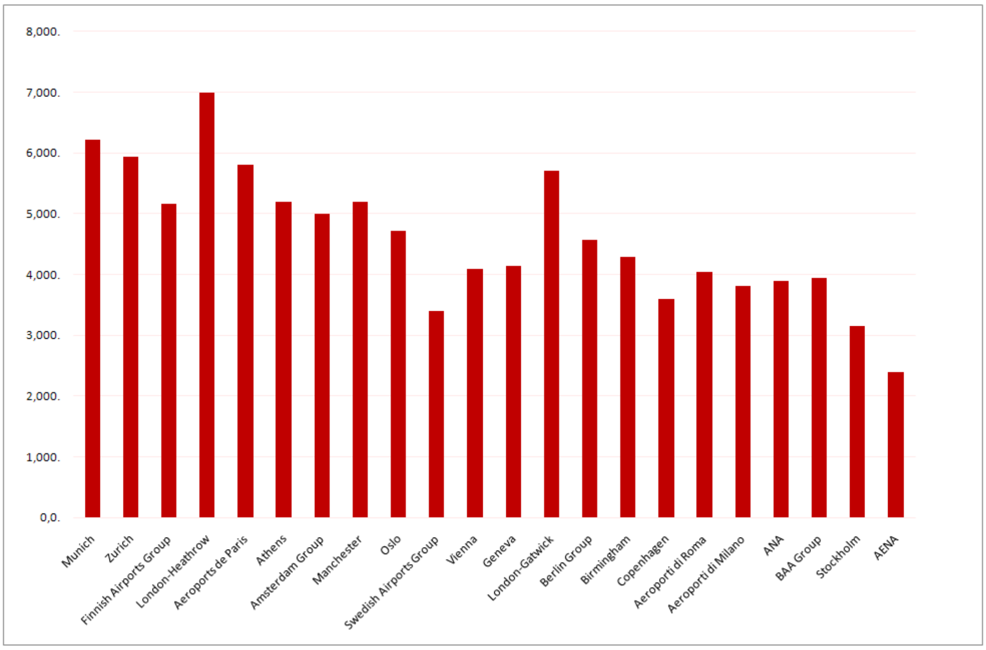
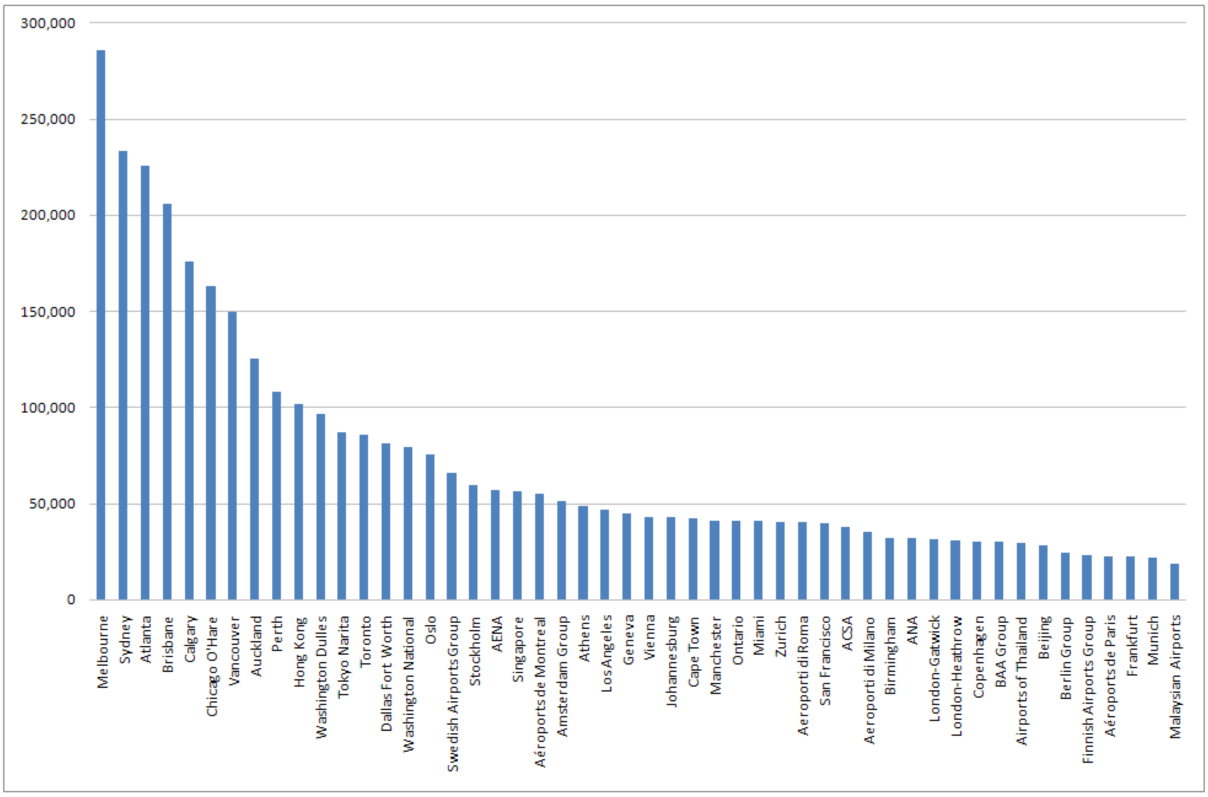


Figure 4.4: ATUs per employee: sample of European airport operators



4.2.3.3 2009 ATRS Global Airport Benchmarking Report

The ATRS Global Airport Benchmarking Report is published every two years and is quite comprehensive in scope. The report encompasses 142 airports (Europe, North America, Asia-Pacific) of varying sizes and measures and compares performance in terms of; productivity, cost competitiveness, financial performance and user charges. The GABR is also different in one other important aspect, because their analysis is two-stage. For each area of analysis, performance measures are computed and then a second stage analysis is undertaken where an attempt is made to identify those variables that influence the performance indicators.

The GABR report adopts a different approach in terms of how it defines the output of an airport. Rather than use the standard WLU or ATU as used in other studies, GABR adopts performance indicators that use a range of different measures of output. The report uses the following measures:

- Passengers
- Work Load Units
- Aircraft movements
- Index of non-aeronautical output
- Output index

The index of non aeronautical output is an aggregate of all the non-aeronautical revenues expressed as a ratio of the non-aeronautical revenues generated by a base airport, which was in this case Vancouver. The output index is formed by aggregating passengers, movements and non-aeronautical output using a mathematical transformation through a translog multilateral indexing formula devised by Caves, Christensen and Diewert (1982).

The report adopts the following measures of performance:

Table 4.4: ATRS performance measures

Productivity	Cost competitiveness
Passengers per employee Aircraft movements per employee WLU per employee Overall labour productivity Passengers per gate Passengers per Terminal m2 Aircraft movements per runway Soft cost input productivity Variable factor productivity	Labour cost per passenger Labour cost per aircraft movement Labour cost per WLU Variable cost per passenger Variable cost per aircraft movement Variable cost per WLU Unit variable cost index

In terms of productivity measures, GABR uses similar measures to that adopted by previous studies. Where it innovates is in the use of three new physical measures, passengers per gate, passengers per m^2 terminal space and aircraft movements per runway, all three being computationally very simple and intuitively very easy to comprehend. GABR introduces two new productivity measures, soft cost productivity and variable factor productivity.

Soft cost refers to airport operating costs other than labour and capital (depreciation) which would, for a typical airport, include the costs of procuring out-sourced activities, consultant services, materials and supplies, utility consumption, repair and maintenance. The soft cost input productivity index for an airport is calculated by deflating all non-labour and capital costs by use of a Purchasing Power Parity exchange rate and then normalising this to a regional mean. The soft cost productivity index is derived by relating the soft cost productivity input index with the various measures of output. The GABR produces soft cost productivity indices based on both passenger volume and the output index (this incorporates air transport movements and non-aeronautical revenues). Table 4.5 below lists the 2007 soft cost productivity – overall output indices for Oslo and a selection of comparably-sized European airports. In terms of soft cost productivity, Oslo appears ahead of its closest peers with the exception of Copenhagen which is ranked the highest in the European sample.

Table 4.5: Soft cost productivity

Airport	
Copenhagen	1.000
Oslo	0.512
Vienna	0.449
Helsinki	0.402
Athens	0.346
Dublin	0.337
Stockholm	0.305

Airports that generate high levels of labour productivity are usually those airports that have outsourced a significant proportion of their operations to third party suppliers. Labour productivity is not suitable because it is partial and cannot provide a measure of the overall efficiency or productivity of an airport unit. An aggregate measure would incorporate all inputs and this would be related in some way to output. Variable factor productivity (VFP) is used by GABR, to provide a higher level aggregation and it involves combining labour and soft costs which are essentially costs that are variable. Capital costs represented by depreciation are not variable and therefore they are excluded from this measure. Both labour and soft costs are combined by using their relative cost shares as weights in the aggregation process which relates this to the combined output index. Using this measure, Oslo has the second highest variable factor productivity with a score of 1.132 behind the leading airport Madrid which scored 1.178. The mean score for all European airports was 0.650.

GABR then attempts to examine the relationship between the various measures of productivity and a range of potential influencing factors.

Labour productivity was found to have some relationship with airport size and proportion of international passengers. Those airports with higher volumes of international passengers, requiring more resource inputs, had lower levels of labour productivity. The same observation can be made with regard to soft cost productivity

In terms of the capital measures of productivity such as Passengers per gate, a very positive relationship was identified between each of these measures and airport size with larger airports achieving higher levels of capital productivity.

Because variable factor productivity can be influenced by effects that are outside of the control of airport managers such as the composition and mix of traffic, the GABR attempts to estimate a residual VFP using multiple regression analysis by isolating and removing the effects of exogenous variables. These are:

- % international passengers
- % cargo traffic
- Aeronautical revenue %
- Average aircraft size
- General economic conditions (represented by dummy variables for the years 2002-2007)

With the exceptions of general economic conditions, the relationship between VFP and all other exogenous variable was found to be statistically significant. Little difference was found in the relative rankings of airports when using both gross VFP and residual VFP measures.

As far as measuring cost competitiveness is concerned, the GABR provides a comparison of airport unit costs. These are listed in Table 4.5 above. Oslo's labour cost per WLU is actually very competitive, with the 4th lowest in the sample of European airports. A similar outcome is also apparent when measuring labour cost per ATM.

Variable cost per passenger, incorporates both labour and soft costs but excludes capital costs such as depreciation. Oslo recorded $12.84 in 2007 compared to a European mean of $16.25 while the same airport recorded a variable cost per ATM of $1,131 compared to a sample average of $1,463.

4.2.4 Summary of the PPM approach and data availability

Most airport operators normally publish detailed traffic statistics and information can be obtained from annual financial reports on total costs, operating costs, labour costs and depreciation. Also included in these annual financial reports is data on staff employed by the airport authority. With respect to Avinor, they publish an annual financial report which provides data which is aggregated across all airports. With respect to the availability of individual financial information for each airport, we have been assured by Avinor that it will be possible to obtain the necessary information from individual airports should it be decided that there will be a comparison of individual airports.

Data requirements are more challenging when benchmarking between airports that are managed within large national networks. Apart from traffic data, which is usually available at an individual airport level, financial and employee data disaggregated by individual airport may be more difficult to obtain. Some operators, such as Swedavia

(Luftfartsvärket (LFV) until 1st April 2010) in Sweden, publish some information on their individual airports. This is shown in the extract from the 2008 LFV annual report shown in table 4.6 below.

Data on staffing, capital expenditure, revenue and profit is clearly available. This would imply that Swedavia has an internal accounting system that has established profit centres at each airport where more detailed cost information could be obtained. Availability of this data and more detail on the degree of out-sourcing and other pertinent items of information would only be forthcoming with the cooperation of Swedavia.

Table 4.6: Data from Sweden (LFV)

Airport statistics, 2008

	PASSENGERS				*LANDINGS*		*STAFF*	*FINANCIAL DATA*		
	Total number	*Change*	*of which internat., number*	*Change*	*Total number*	*Change*	*Full-time equivalent number*	*Capital-spending, SEK M*	*Sales, SEK M*	*Profit,[1] SEK M*
Stockholm-Arlanda Airport	18,136,105	1.2%	13,281,295	3.2%	111,450	2.0%	815	516	2,921	613
Göteborg Landvetter Airport	4,303,741	-1.2%	3,158,832	1.5%	32,813	2.0%	469	142	682	193
Malmö Airport	1,748,357	-6.5%	666,218	-9.7%	18,810	-6.1%	104	27	257	29
Stockholm-Bromma Airport	1,855,949	2.8%	145,526	4.8%	31,372	1.0%	113	34	226	31
Luleå Airport	995,663	7.0%	58,231	-1.5%	9,524	9.1%	41	6	93	1
Umeå City Airport	823,317	1.6%	43,164	1.7%	10,840	-0.4%	85	14	98	10
Ängelholm Helsingborg Airport	391,372	-0.8%	5,096	-43.0%	7,367	8.0%	32	8	42	-87 [1]
Åre Östersund Airport	383,419	2.4%	17,736	-20.4%	4,028	-3.4%	38	0	40	-18
Visby Airport	324,465	2.2%	12,732	-5.3%	9,775	-5.4%	40	2	38	-9
Sundsvall Härnösand Airport	303,629	-9.7%	25,646	23.5%	5,821	-10.4%	49	2	54	-110 [1]
Skellefteå Airport	241,962	2.6%	10,342	-14.9%	3,338	-11.7%	36	3	29	-65 [1]
Kiruna Airport	207,432	8.4%	5,709	123.4%	3,381	7.7%	16	1	38	-20
Ronneby Airport	206,940	-5.7%	2,076	34.4%	5,162	45.8%	5	2	21	-8
Örnsköldsvik Airport	145,710	10.0%	3,152	-5.0%	2,040	21.9%	32	7	25	-57 [1]
Karlstad Airport	118,909	-0.2%	62,010	7.9%	5,247	-0.7%	35	3	27	-54 [1]
Jönköping Airport	76,611	-28.5%	23,461	-41.0%	7,297	1.9%	31	1	29	-52 [1]

1 Including the write-down of fixed assets at the six airports that, according to Parliament's decision, are not proposed as part of the national basic airport infrastructure.

Finavia, like both Avinor and Swedavia is a state-owned enterprise that operates a network of airports. Traffic information is available for their individual airports. Financial accounts for Finavia airports are consolidated in their annual report. However, they can provide 10 years of financial information and human resources data for each of their 25 airports, even if the material is not presented in annual reports. Operational data for each of Finavia's airports (e.g. on terminal space, runways, staff) is available.

Because the UK airport industry is largely privatised and deregulated, airports are owned separately and both detailed financial and traffic statistics are readily available for most airports.

A challenge in terms of data is to obtain individual cost centre data for each airport for standardisation and normalisation purposes. For example, one unknown/risk factor would be the degree to which it would be possible to obtain information on the revenues, costs, and employees associated with a small Swedish airport's ground handling activities for the purposes of normalisation.

Table 4.7 below provides a list of performance indicators, the data needed to calculate these indicators and their respective sources. For the majority of performance indicators, one would expect most data sources to be accessible, primarily through various published sources either through the operators themselves or through trade associations such as ACI. At an individual airport level, traffic statistics are usually very accessible either through ACI publications (World Air Traffic Report) which have consistent reporting formats, through national civil aviation regulators or from individual airport traffic reports which are normally available for download on respective websites. However, the availability of financial data, especially on cost depends on whether the airport is managed by a national system operator such as Avinor (where we are confident that this kind of operators with few exceptions would share their data even if they are not published) or whether the airport it is managed by a single operator. For the independently operated airports it is unusual for individual airport financial data to be published and therefore approaches to individual airport would be necessary and success therefore entirely dependent on good-will. The same is true with regard to physical data such as number of gates and total terminal space. In this case, there is no single published source and a researcher would therefore have to approach airports individually or obtain such information from websites.

Given that data is accessible, partial measures are intuitively very easy to compute, understand and interpret. Judgment would need to be made on whether to normalise the data as done in previous studies in order to take into account differences in the degree of outsourcing between airports. However, as the benchmarking exercise itself is measuring the outcome of managerial decision-making i.e cost-efficiency, out-sourcing services will have an effect on performance and should ideally be incorporated in the analysis. The exception would be in the case of air traffic control where local regulation requires that the national air navigation service provider provides terminal area air traffic control. In these cases airports are not able to exercise the choice to out-source. In this case normalisation of the data would become necessary.

Their one significant limitation is that they are less effective in providing a robust assessment of an airport's overall performance especially within the context of measuring the performance of the airport in relation its optimum potential performance. More sophisticated techniques are able to do this.

Indicator	Data needed	Source	Comments
Labour cost per passenger	Labour costs Passenger traffic	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Labour cost per ATM	Labour costs ATM data	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Labour cost per WLU	Labour costs Passenger traffic Cargo traffic	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Variable cost per passenger	Variable costs Passenger traffic	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Variable cost per aircraft movement	Variable costs ATM data	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Variable cost per WLU	Variable costs Passenger traffic Cargo traffic	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results. Use of PPP or SDR currency recommended
Unit variable cost index	Variable cost Passenger traffic Cargo traffic ATM data Non-aeronautical data	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR	Easy to compute and understand Output index derived by multilateral translog indexing procedure developed by Caves et al (1982).
Passengers per employee	Employee data Passenger traffic	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results.
Aircraft movements per employee	Employee data ATM traffic	Airport annual report Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results.

WLU per employee	Employee data Passenger traffic Cargo Traffic	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR	Easy to compute and understand. Need to obtain information degree of outsourcing to interpret results.
Overall labour productivity	Employees Passenger traffic Cargo traffic ATM data Non-aeronautical data	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR	Easy to compute and understand Output index derived by multilateral translog indexing procedure developed by Caves et al (1982).
Passengers per gate	Passenger data Number of gates	Airport traffic report or ACI WATR Direct contact with airport	Easy to compute and understand. No public source of data available on gates per airport. Information obtained from direct contact with airports or internet searches
Passengers per Terminal m2	Passenger data Number of gates	Airport traffic report or ACI WATR Direct contact with airport	Easy to compute and understand. No public source of data available on gates per airport. Information obtained from direct contact with airports or internet searches
Aircraft movements per runway	ATM data Number of runways	Airport traffic report or ACI WATR Internet / various published sources	Easy to compute and understand. Information on number of runways avialble from various published sources (e.g. national aeronautical information publications)
Soft cost input productivity	Soft costs Passengers ATMs Non-aeronautical revenues	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR Airport annual report	Requires mathematical transformation of inputs and outputs using translog multilateral indexing formula.
Variable factor productivity	Labour & Soft costs Passengers ATMs Non-aeronautical revenues	Airport annual report Airport traffic report or ACI WATR Airport traffic report or ACI WATR Airport annual report	Requires mathematical transformation of inputs and outputs using translog multilateral indexing formula.

Table 4.7: Indicators and sources

State / airport operator	Group annual report	Individual airport traffic data	Individual airport financial data	Individual airport capacity data	Comments	Contact
Avinor	Published	Published	Available on request	Available on request		Knut Fuglum
Swedavia (Sweden)	Published	Published	Limited amount published	Data needs to be requested	Separation of airport ATC data required	
Swedish regional airports	n/a	Published	Data needs to be requested	Data needs to be requested		John Bennett (Swedish association of municipal airports)
Finavia (Finland)	Published	Published	Data needs to be requested	Data needs to be requested	Separation of airport ATC data required	Ari Haapanen
Aena (Spain)	Published	Published	Data needs to be requested	Data needs to be requested	Separation of airport ATC data required	No contact
ANA (Portugal)	Published	Published	Data needs to be requested	Data needs to be requested	Separation of airport ATC data required	
Highlands and Islands airports	Published	Published	Limited amount published	Data needs to be requested		Inglis Lyon
Other UK airports	n/a	Published	Published	Data needs to be requested		No contacts needed
Dublin Airport Authority	Published	Published	Data needs to be requested	Data needs to be requested		Various
Irish regional airports	n/a	Approach to Department of Transport	Data needs to be requested	Data needs to be requested		Department for Transport
Danish regional airports	n/a	Published	Data needs to be requested	Data needs to be requested		No contact
Isavia (Iceland)	Not published	Data needs to be requested	Data needs to be requested	Data needs to be requested		Mr Thorgeir Palsson

Table 4.8: Data issues by airport operator / system

4.3 More sophisticated measures of efficiency measurement

4.3.1 Theory

Efficiency measurement is a way of monitoring the performance of a unit of production as compared to others in the same industry performing the same types of operations. An example would be efficiency measurement of airports controlled by Avinor. In such a case an efficiency measurement procedure would be to identify best performers, the so-called efficient airports, and then compare the performance of the others relative to these best performers. For governments such as the Ministry of Transport and Communications, efficiency measurement can serve several purposes, e.g., (1) facilitate the monitoring of Avinor's managerial performance, hence improve the accountability of the ministry, (2) promote "yardstick competition" by providing a means for comparing the performances of similar service providers such as airports, and (3) assist the allocation of resources by providing a means for allocating funds based on agreed plans for improved performance. Notwithstanding, efficiency measurement is also a powerful tool for agencies such as Avinor and its individual service providers such as airports. For example, managers of Avinor can use efficiency measurement to identify differences in performances among airports, and they can use it to improve the efficiency of the sector.

This theoretical section describes the different methods that are available in the literature of applied economics for measuring efficiency in the service sectors such as Avinor. The chapter proceeds as follows: First it defines the concepts that are interchangeable used to mean the same thing as efficiency such as productivity and effectiveness. Second, it defines the different forms of efficiency e.g., technical, allocative, cost and scale efficiency measures. Third, it describes the different methods of efficiency measurements such as Data Envelopment Analysis and Stochastic Frontier Analysis. Fourth, it draws some conclusions with regard to the best method that should be used for assessing the efficiency of Avinor. Finally, measuring efficiency over time is considered.

4.3.1.1 The concepts of productivity, effectiveness and efficiency

Assessing performance of production units is a complex task and there are many terms used to refer to it. Efficiency for instance is a term used to refer to how well a unit of production is performing. Other terms frequently used interchangeably with efficiency includes Productivity, Total Factor Productivity (TFP), Partial Productivity Measures (see Section 4.2), Effectiveness and Efficiency. It is therefore important to make a distinction between these terms, especially in the way we intend to use them here; in order to avoid misunderstandings.

Productivity refers to the ratio between output(s) and input(s). If for instance, one is comparing two units of production, the one with the highest output/input ratio is considered to be more productive than the other. Note that this is irrespective of whether outputs/inputs are measurable in monetary terms or not. Furthermore, productivity defined in this way has no upper limit such as how high the output/input ratio must be in order to be efficient.

Total Factor Productivity (TFP) comes to use when there are many outputs and inputs and some aggregation is required to derive a measure of productivity. It is the ratio of the quantity of all outputs to the quantity all inputs that is used to derive one measure or indicator of productivity. The most common way of aggregating inputs or outputs is by using price data such as the cost shares or revenue shares, respectively.

Partial productivity measures (or indicators) are a concept that refers to measuring productivity in part for the reason that not all outputs/inputs can be aggregated to form one index for productivity. For, example output per employee does not include all factors required to produce airport services such as capital. It is thus a partial productivity measure (see Section 4.2 for more details).

Effectiveness, unlike productivity, refers to the degree to which the outputs of a service provider achieve the stated objectives of that service. For example, the Ministry of Transport and Communications may state objectives to be met by Avinor such as maximum waiting time for luggage at airports. Effectiveness is thus a measure of how these objectives are met.

Efficiency builds on the concept of productivity defined above. It refers to the degree to which productivities defined above -including all inputs and outputs that matters - matches the optimal productivities. It is thus a relative measure where productivities are related to some production frontier; either constructed from best practices or constructed econometrically using some known or accepted functional forms.

From the definitions above, it is clear that productivities (either total or partial) does not measure efficiency for the simple reason that they do not relate to a given standard i.e., how large they should be in order for a unit of production to strive to be efficient according to some rule of measure. To this end, efficiency measurement is the appropriate measure of performance. Furthermore, although partial productivities measures are easy to understand, often easy to compute and may serve specific purpose such as evaluation of a specific process within an airport, they do not adequately represent the aggregate efficiency of service production such as an airport. This is because airports, like any other complex economic entities, transform multiple inputs into multiple outputs. Researchers have therefore developed several other alternative approaches to measuring efficiency.

4.3.1.2 Different efficiency concepts

Before discussing the methods for efficiency measurement it is necessary to look at the different concepts of efficiency in the way they appear in the literature of economics and which could be of interest to measure.

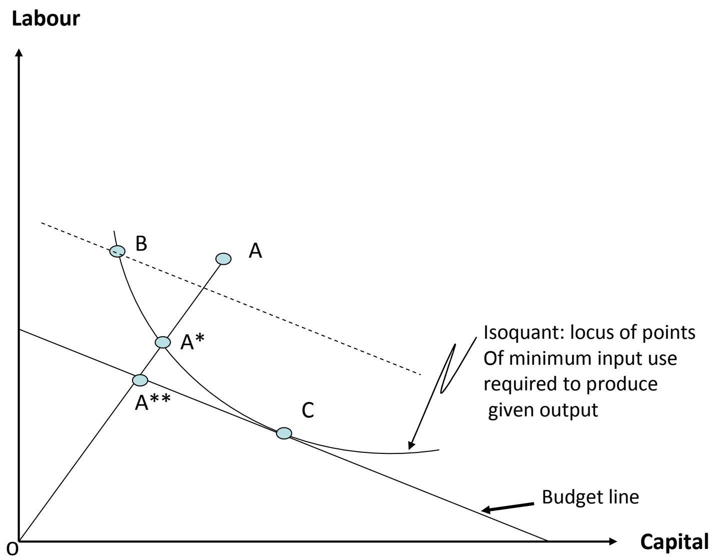
The most common efficiency concept is *technical efficiency* which refers to the conversion of physical inputs, such as labour and capital, into outputs relative to best practice. Airports or airport authorities that operate at best practice are said to be 100% technically efficient, i.e. they do not waste resources. Any airport that operates below best practice (which can be one airport or a group of airports) is said to be technically inefficient and the airports technical efficiency is expressed as a percentage of best practice. Technical efficiency will be affected by scale or size of operations since it is based on engineering relationships but not on prices and costs.

The second efficiency concept is *allocative efficiency* which refers to whether inputs, for a given level of output and set of input prices, are chosen to minimize the cost of production assuming that the airport being examined is fully efficient. As opposed to technical efficiency, which shows excess use of inputs, allocative efficiency shows whether the right mix of inputs are chosen. It is also expressed as a percentage of scores where 100% indicates that airport is using its inputs in the proportions which minimize its costs; it is allocatively efficient. It should be noted that an airport that is operating at best practice in terms of technical efficiency could still be allocatively inefficient since it is not using its inputs in the proportion that minimizes its costs, given the relative input prices.

The last efficiency concept is the *cost efficiency* which refers to the combination of technical and allocative efficiency. An airport will be cost efficient if it is both technically and allocatively efficient. Cost efficiency is calculated as the product of technical and allocative efficiency scores expressed as a percentage. Thus, an airport can only achieve a 100% cost efficiency score if it is has achieved 100% scores in both technical and allocative efficiency.

The three efficiency concepts are illustrated in figure 4.5. The inputs we consider are labour and capital that are required to produce airports services, e.g. number passengers handled. The curve plotted in the figure is the isoquant: it plots the minimum amounts of labour and capital required to produce a given output quantity (a given number of passengers handled). It is thus also called the *technical efficiency frontier*. If an airport (or organization in question) is producing at a point on the curve such as B, A* or C, then that airport is technically efficient as opposed to point A which is technically inefficient. The straight budget line plots the combination of labour and capital that have the same cost. The slope of this budget line is given by the negative of the ratio of capital price to the labour price. A budget line closer to the origin implies lower total cost. It follows that the cost of producing a given output is minimized at the point where the budget line is tangent to the isoquant (efficiency frontier); at this point, technical and allocative efficiency are attained.

Figure 4.5: Illustration of different efficiency concepts



Now consider the points marked A, A*, A**, B and C in the figure. An airport operating at point A would be technically inefficient because it uses more inputs than required to produce at the frontier (isoquant). An airport at point B would on the other hand be technically efficient but not cost efficient. B could for example, maintain its level of production while producing at a less cost by moving to point C. An airport operating at C is both technically and allocatively efficient and hence, also cost efficient. There is a way of calculating the efficiency scores for individual units of production such as those plotted in the figure. Suppose an airport situated in A moved to point C in order to be cost efficient; by how much would its cost efficiency increase? Because it is both technically and allocatively inefficient, it would have to improve in both to be cost efficiency. In terms of technical efficiency it will have to increase efficiency by the distance $\frac{\left(OA-OA^{*}\right)}{OA}$ to reach the frontier. In terms of allocative efficiency it will have to increase efficiency by $\frac{\left(OA^{*}-OA^{**}\right)}{OA^{*}}$. Since the cost efficiency is the product of technical and allocative efficiency, its cost efficiency will increase by $\frac{\left(OA-OA^{*}\right)}{OA}\times\frac{\left(OA^{*}-OA^{**}\right)}{OA^{*}}=\frac{\left(OA-OA^{**}\right)}{OA}$.

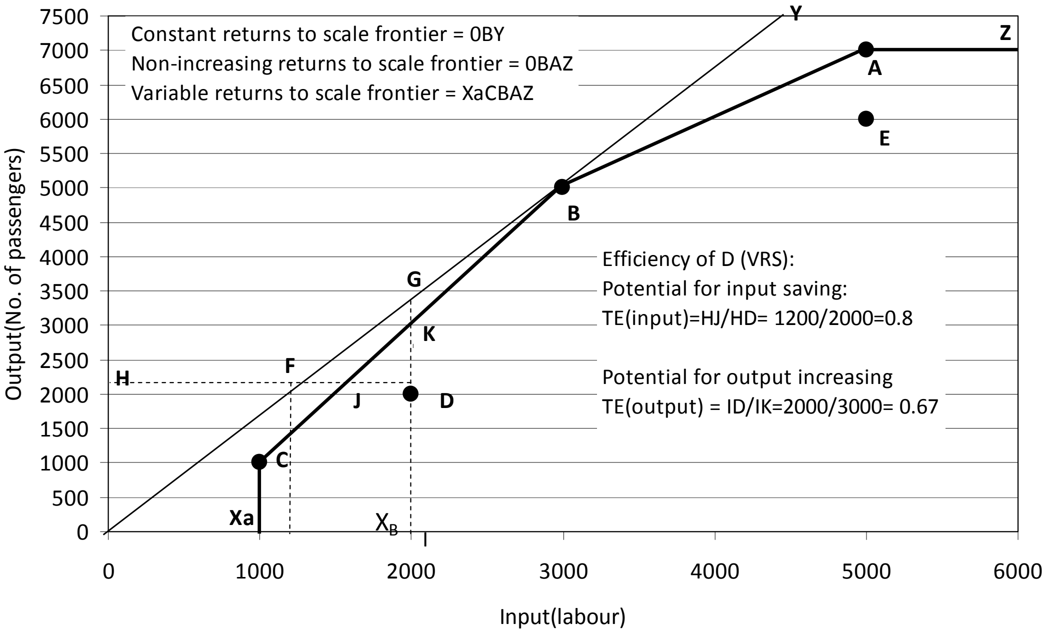
It is worth noting that cost efficiency is the superior efficiency concept because the use of inputs (technical efficiency) and the efficient input mix (allocative efficiency) is measured at the same time. We can say that technical efficiency is a necessary but not sufficient condition for cost efficiency to be fulfilled. In other words, one cannot obtain cost efficiency without having the technical efficiency in place, but technical efficiency can be present even if the mix of inputs is not cost efficient.

Returns to scale is another important concept of efficiency measurement. It refers to changes in output subsequent to a proportional change in all inputs (where all inputs increase by a constant factor). If output increases by that same proportional change then there are constant returns to scale (CRS). If output increases by less than that proportional change, there are decreasing returns to scale (DRS). If output increases by more than that proportion, there are increasing returns to scale (IRS). Variable returns to scale occur when there is a mix of all the aforementioned. The example illustrated in Figure 4.5 above was based on the assumption of constant returns to scale. This assumption essentially means that the size of production units is considered irrelevant when measuring relative efficiency; while in practice size may matter. If for example, it is assumed that all the Avinor's airports operate with constant returns to scale, it means that doubling of inputs will double output irrespective of the size of the airport. This will imply that there are no economies or diseconomies of scale in Avinor's airports. Obviously such an assumption would be unrealistic. Some airports would be too small and therefore operates with increasing returns to scale while other could, at least in theory, be too large and therefore operates with decreasing returns to scale.

It would be to the airport's advantage to operate with optimal scale; neither too small if there are increasing returns scale and neither too large if there are decreasing returns to scale. Thus, when assessing efficiency, both technical and scale efficiency should be examined.

The concept of scale and how it relates to CRS and VRS frontiers can be demonstrated using a simplified one input (labour cost) and one output (number of passengers) case as shown in Figure 4.6. Five airports, A, B, C, D, E are being evaluated.

Figure 4.6: Production frontier and returns to scale



The line 0BY represents the constant returns to scale (CRS) frontier while XaCBA represents the variable returns to scale (VRS) frontier. The distance from the respective frontiers determines technical efficiency under each assumption. Any efficient airport with respect to the CRS will naturally also be scale efficient. Thus, scale efficiency is calculated as the distance between the constant and variable returns to scale frontiers. Consequently, airport B is the only airport that is scale efficient. Airports A and C are technically efficient according the VRS frontier, but are not scale efficient. Consider now how the efficiency, using all the scale concepts, can be derived for airport D which is not efficient according to any of the frontiers. The following efficiency measures can be calculated for it:

- $\text{Input saving efficiency}(\text{CRS}) = \dfrac{\text{HF}}{\text{HD}} = \text{Output increasing efficiency}(\text{CRS}) = \dfrac{\text{X}_\text{B}\text{D}}{\text{X}_\text{B}\text{G}}$
- $\text{Input saving efficiency}(\text{VRS}) = \dfrac{\text{HJ}}{\text{HD}}$
- $\text{Output increasing efficiency}(\text{VRS}) = \dfrac{\text{X}_\text{B}\text{D}}{\text{X}_\text{B}G}$
- $\text{Scale efficiency} = \dfrac{\text{HF}}{\text{HJ}} = \dfrac{\frac{\text{HF}}{\text{HD}}}{\frac{\text{HJ}}{\text{HD}}} = \dfrac{CRS\ efficiency}{VRS\ efficiency}$

It follows that scale efficiency is calculated as the ratio of CRS to VRS efficiency scores or that inefficiency is composed of two parts; pure technical inefficiency (HJ/HD) and scale inefficiency (HF/HJ). For airports A and C, they are technically efficient but not scale efficient. A operates with decreasing returns to scale and hence could reduce its size to be scale efficient. C on the other hand operates with increasing returns to scale and could increase its size to be scale and fully efficient.

4.3.1.3 The Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is regarded as one of the most successful techniques of efficiency assessment proposed by researchers in Management Science and Operations Research, as is evident by the diversity of its application, also in the aviation sector (see Section 4.3.2). DEA is a linear programming approach used to calculating the efficiency of an organisation within a group relative to best observed practice within that group. The organisations can be whole agencies (for example, airport authorities such as Avinor), separate entities with the agency (for example, airports managed by Avinor) or disaggregated business units within the separate entities (for example, terminal activities of an airport). DEA was first used in the investigation of non-profit organizations whose performance cannot be measured by a single measure such as profit, but along several dimensions. In the last three decades, it has become the most popular method for assessing efficiency of almost all sectors of production e.g., transportation, health, agriculture, banking etc.

DEA proceeds by defining the best practice frontier composed of the most efficient units. The relative efficiencies of the remaining units are measured as a distance from this frontier. The best practice frontier is non-parametric, i.e. no functional form needs to be specified or assumed, in contrast to other parametric production frontiers such as Stochastic Frontiers Analysis (SFA). The DEA method allows for the incorporation of multiple outputs and inputs. Inputs may be variable and fixed, where the values of the variable inputs are allowed to change in the short run (in the airport industry inputs are e.g., number of employees, and number of check in desks) while the values of the fixed inputs are only allowed to change in the long run (fixed inputs are e.g. number of runways). The DEA method can be input or output orientated, of which the former determines the minimum input for which the observed production of a unit is possible, while the latter determines the maximum output of the unit given the observed inputs.

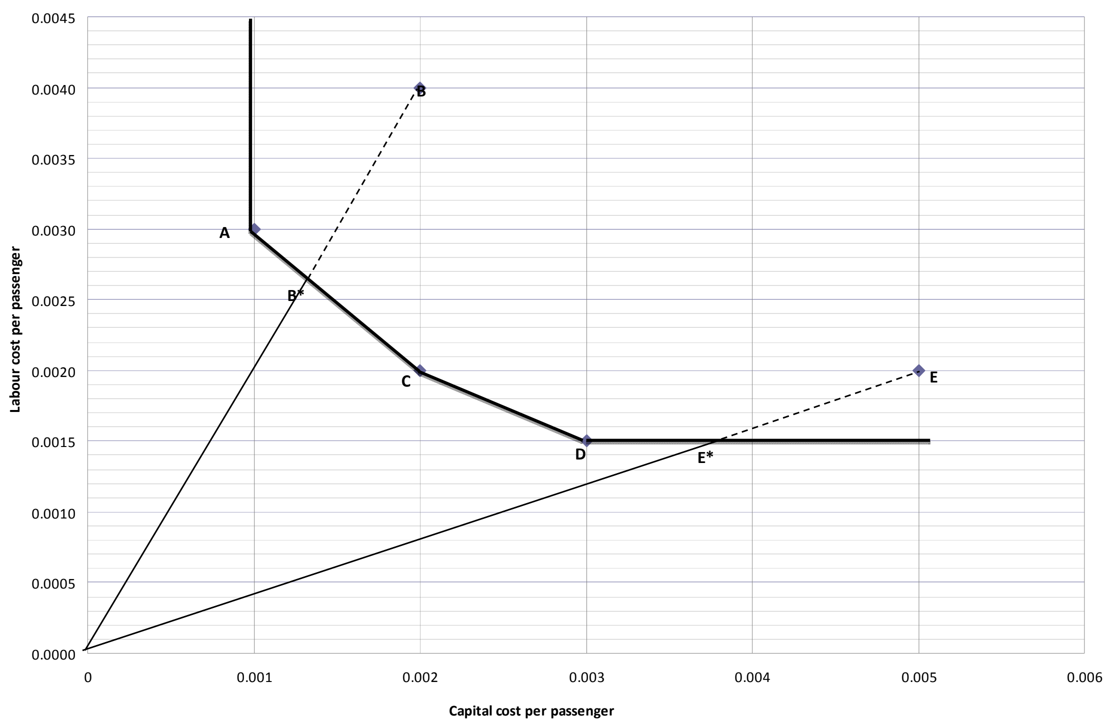
To demonstrate the workings of DEA in calculating the efficiency of comparable units in an industry such as airport or aviation industry, we consider a simple numerical example: a sample of five hypothetical airports that use two inputs, labour and capital, to produce one output - number of passengers handled at the airport. Obviously, the inputs and outputs of a real airport are considerably much more complex, but this simplification is a good starting point for actual as well as illustrative purposes. The data for the five hypothetical airports are presented in Table 4.9.

Table 4.9: Illustrative hypothetical data on five airports

	Output	*Inputs [in mill NOK]*		*Input/output ratios*	
	Number of passenger(O1)	*Labour costs(I1)*	*Capital costs (I2)*	*I1/O1*	*I2/O1*
Airport A	200 000	200	600	0.001	0.003
Airport B	300 000	600	1200	0.002	0.004
Airport C	100 000	200	200	0.002	0.002
Airport D	200 000	600	300	0.003	0.002
Airport E	100 000	500	200	0.005	0.002

The five airports range in size from 200 to 600 in terms of labour costs and there is similarly a large variation in capital costs. Given the large discrepancies among the five airports' characteristics, it is not obvious how to compare them or which airports should be a role model for others to improve their performances. This is where the workings of DEA comes to use; the answers to the questions become clearer when the input/output ratios - labour costs per passenger and capital cost per passenger - are plotted as in Figure 4.7. It is intuitively obvious that the smaller the output/input ratios, the more efficient the airport must be. Thus the airports closest to the origin and the two axes are the most efficient.

Figure 4.7: Illustrating airport efficiency measurement using DEA



The line A, C, D represents what is known as the “best-practice frontier”. Points on this frontier are considered to be 100 % efficient. The best practice airports are therefore airports A, C and D; they all have an efficiency rating of 1.0 (i.e. they are 100 % efficient). All other airports north-east of the frontier are considered inefficient and will have an efficiency rating of less than 1.0; they use more inputs (labour and capital) to produce handle the same number of passengers as the airports on the frontier. They thus can be able to reduce their input use (labour and capital) and still maintain their output levels as compared with best practice airports.

Consider airport B, who uses more inputs than is required to be on the frontier. The efficiency rating for airport B is the ratio of the distance of the line segment from the origin to point B* and from the origin to point B (the ratio of best practice to observed inputs). The efficiency of airport B is thus calculated as:

$$E_B = \frac{0B^*}{0B}$$

In Figure 4.7, the above ratio is found to be $\frac{0.0027}{0.004} = \frac{0.00135}{0.002} = 0.67$; this means that airport B has an efficiency score of 0.67. Hence, the input-saving potential for airport B, the percentage by which the airport would have to reduce its inputs to achieve the best practice frontier is 33 % (1-0.67). The same reasoning can be used to derive the efficiency score and input-saving potential for another inefficient airport E; the efficiency score and the potential for input-saving respectively $\frac{0.0015}{0.002} = \frac{0.001375}{0.005} = 0.75$ and hence an efficiency potential of 25%.

Now it is worth noting that DEA has another important feature, especially as far as benchmarking is concerned. Consider the case of inefficient airport B. Intuitively; we see from Figure 4.7 that it is aiming to produce the same results as A and C who are on the frontier. However, its airport of comparison has been a "virtual or hypothetical" airport B*. The virtual airport B* is a combination of or a weighted average of the operations of airports A and C. If airport B is to be benchmarked against any other airports as role models to improve performance, then it should examine the operations of airports A and C because these are the most efficient airports similar to itself; its peers' . Thus, DEA as method of efficiency assessments is able to identify the peers of which the inefficient airports can be compared to in order to learn and improve.

The DEA example above is relatively easy to understand and implement, especially in a two-dimensional diagram as in Figure 4.7. However, when the there are many inputs and outputs as often is the case for airport services, DEA method is no longer amenable to simple graphical analysis. It is necessary to use linear programming techniques and computer packages to solve for the efficiency scores and potential for improvements for the individual airports that are being compared. We briefly present here the linear programming (LP) problem devised by Charnes, Cooper and Rhodes (1978); hereafter (CCR), for finding the efficiency score (E_i) for an airport *i*:

$$
\left.
\begin{aligned}
&\text{Min } E_1 \\
&\text{s.t} \sum_{j=1}^{n} \omega_j x_j - E_1 x_o = - s_j^- && \text{(a)} \\
&\sum_{j=1}^{n} \omega_j y_j - y_o = s_j^+ && \text{(b)} \\
&\omega_j \geq 0, \ j = 1,\dots, n && \text{(c)}
\end{aligned}
\right\}
$$

where x_0 and y_0 respectively, denote the input and output vectors for selected airport. E_1 is the input saving efficiency measure of unit 0 under evaluation. ω_j is the non-negative weight of unit J's outputs and inputs that defines a comparison point on the frontier. Restriction (a) states that the efficiency-corrected use of inputs ($E_1 x_0$) must at least equal the amounts employed by the reference company. Constraint (b) states that the reference company must produce as much output as Company J. Please note that the CCR formulation is non-flexible in the sense that it assumes constant returns to scale (CRS) in its production possibility set. It can, however, be modified to include variable returns to scale (VRS); see Banker et al. (1984), hereafter BCC. This modification implies adding a convexity constraint limiting the summation of the multiplier weights (ω) equal to 1, i.e., including $\sum_{j=1}^{n} \omega_j = 1$ in the model above. The linear program above is run sequentially for each of (n) airports. Technically, efficient airports are identified in units that have input and output slack vectors $s_j^- = 0$ and $s_j^+ = 0$ in addition to $E_1 = 1$ at optimality. These best practice airports display either an optimal composite of inputs (or outputs) or a single exceptional input-output ratio. Less efficient airports will obtain a z-score of less than 1 and might have non-zero input or output slacks. In order to compute the output-oriented measure E2, the reciprocal of model (1) above may be considered. The objective is then to maximize output within the given finite stock of inputs available.

The technical efficiency derived from CCR and BCC formulations can be used to obtain a measure of scale efficiency as:

$$SE_k = \frac{E_{CCR_k}}{E_{BCCk}}$$

where SE_k indicates the scale efficiency of kth airport, where E_{CCR_k} and E_{BCC_k} are the technical efficiency measures for airport k, derived from applying CCR and BCC formulations respectively. $SE_k = 1$ indicates scale efficiency, and $SE_k < 1$ indicates scale inefficiency. Scale inefficiency, however, is due to either increasing or decreasing returns to scale. Whether IRS or DRS is the case can be determined by inspecting the sum of weights under the CCR formulation:

$$SW = \sum_{j=1}^{n} \omega_j$$

SW= 1 will provide constant returns to scale (optimal scale), SW>1 decreasing returns to scale (superoptimal scale) and SW<1 increasing returns to scale (suboptimal scale).

Now, there may be factors outside the control of the organisation but which may impact efficiency. For instance, weather conditions which are not under the control of airports management may impact the performance of airports. In order to gain the role that external factors play on the efficiency performance of airports, the so-called second stage DEA may be conducted. It entails regressing the efficiency scores obtained from the first stage on the external factors and interpreting the results. The first stage results may then be corrected up or downwards depending on the regression results.

From the expositions above, DEA provides the efficiencies of individual airports or aviation authorities as compared to others and, identifies possible benchmarks towards which performances can be targeted. The weighted combinations of peers and the peers themselves can provide benchmarks for inefficient airports or aviation authorities. The actual level of inputs or outputs of efficient airports can serve as target for the inefficient units and managers can improve by identifying peers and learning from them.

There is a large list of question that DEA can help answers for managers and operators, and that makes it advantageous relative to other methods for efficiency measurements. These are as follows; but the list is not exhaustive:

- How do I combine the many inputs and outputs to form one defensible measure of efficiency?
- How do I derive the most appropriate role models to serve as a possible benchmark for my organisation or unit of production?
- Which are the most productive/efficient units in my organisation or the industry that I belong to, and that I can learn from?
- If my organisation was to perform according to the best practice frontier, how much more output could I produce and/or how much could I reduce my inputs; and with respect to which outputs and inputs?
- What are the characteristics of the best practice organisations and how can they guide in helping my organisation/unit in improving efficiency?
- How do I account for external factors beyond my control that impact on efficiency?

Clearly, the simple DEA model discussed above can help in answering all of these questions making the most powerful tool for assessing efficiency of production while allowing for benchmarking and most importantly, it conforms to economic theory.

After considering an alternative approach to DEA in the section that follows, we revert and explain DEA's advantages over other methods; the reason why we propose it for assessing the efficiency of Avinor.

4.3.1.4 The Stochastic Frontier Approach

A second approach that is common in the assessment of efficiency of production units is the so-called Stochastic Frontier Analysis (SFA); also sometimes called the parametric approach to differentiate it from DEA which is basically a linear programming approach. In relation to Figure 4.6, SFA proceeds by assuming that there is a well defined frontier production function that defines the maximum feasible output as:

$$y_i = f(x_i; \beta) + v_i$$

where y_i denotes output of the i'th producer (airport) ; x_i is a vector of actual input quantities; β is a vector of parameters to be estimated; and v_i is a random error term. SFA defines technical efficiency ($\mathrm{E_i}$) for unit *i* (or airport *i*) as the ratio of observed output to feasible out as:

$$E_i = \frac{Y_i}{f(X_i;\beta)+v_i}$$

It becomes clear that unit *i* (or airport *i*) will achieve its maximum feasible value, I.e, is efficient, only if E_i =1. Otherwise E_i <1 provides a measure for the shortfall of observed output from feasible output just as in the case of DEA. Further, SFA can be formulated to measure all the concepts of efficiency just as DEA can.

The advantages of SFA over other methods until recently, are that it builds on econometrics and therefore it is able to capture noise in the data more adequately as compared to other methods. It should be noted that DEA has recently been developed to account for noise in data and hence SFA is no longer advantageous over it. The major disadvantage of SFA however, is that it requires a functional form to be specified; when measuring efficiency in the service provision sector, it may be difficult to convince the management that their production of services is according to some pre-defined smooth production function that can be expressed mathematically. This is its major disadvantage; for how can one expect managers to follow a mathematically function in the management of their organisations? Further, when there are more than one output, SFA becomes complicated to use aggregation and weighting of outputs must be done.

4.3.1.5 Efficiency over time – the Malmquist Productivity Index

Governments or principals may be interested in investigating how efficiency develops from one year to another. Studying the developments in efficiency over time is one way of investigating the impact that interventions have on the performances of production units. One way of investigating the developments in efficiency over time is to use the so-called Malmquist Productivity Index (MPI). The MPI measures productivity growth from one period to the other as improved efficiency relative to a frontier. Consequently, the MPI can be derived either using DEA or SFA approaches. It is expressed as two adjacent efficiency measures. For airport *i*, the Malmquist Productivity index (MPI) between time periods *t* and *t+1* based on frontier at time *t* is calculated as:

$$MPI_t^i = \frac{E_{t,t+1}^i}{E_{t,t}^i}$$

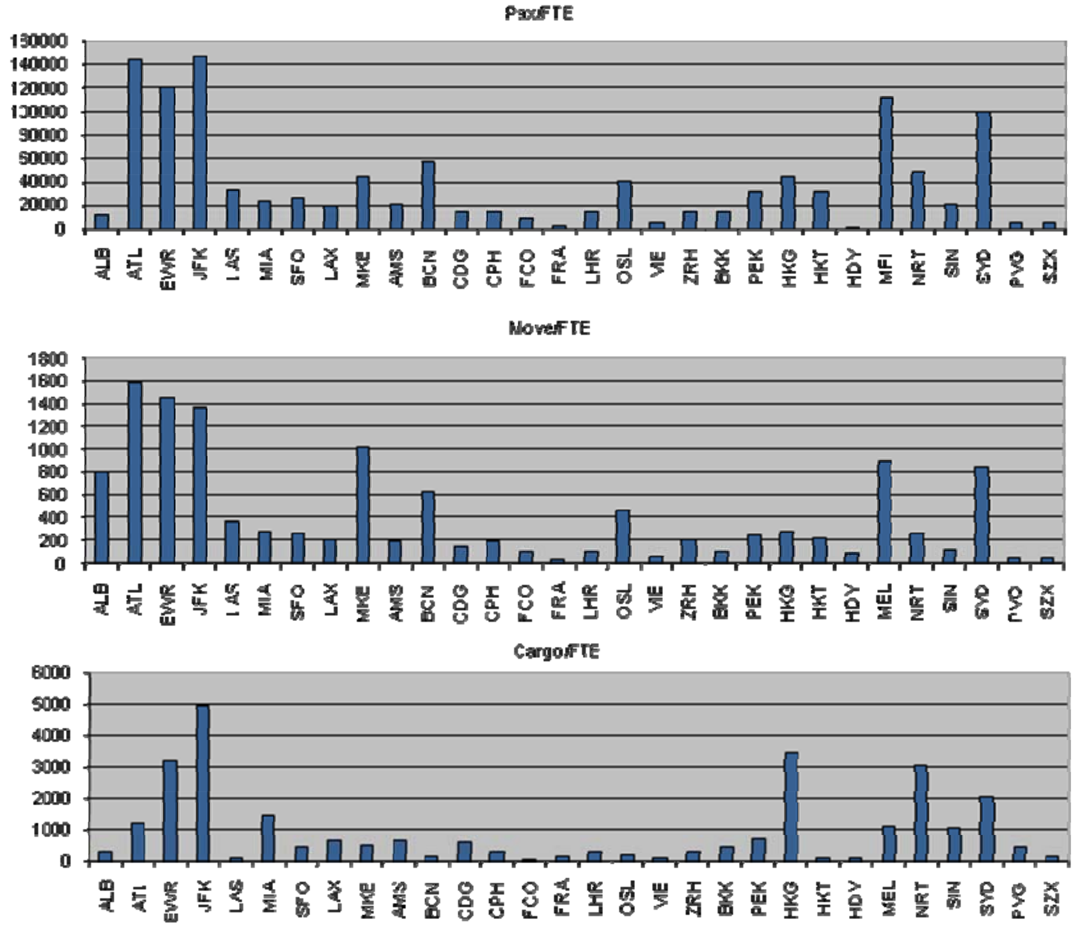
In the equation above, $E_{t,t+1}^i$ and $E_{t,t}^i$ are technical efficiency scores for airport *i* that relates observations in periods *t* and *t+1*, respectively, to period t frontier. Moreover, it has been shown that the MPI can be divided into two mutually exclusive components; one showing productivity growth due to improvement in efficiency while the other shows productivity growth due to technical progress(see for instance Färe et al., 1985). MPI is a product of these two components.

4.3.2 From theory to application

As shown in Section 4.2, partial indicators of performance are the traditional and most commonly used method to compare airports, because they are easy to compute, require only limited data collection, intuitively easy to understand and the results are easy to read as well as easy to interpret. However, if only partial indicators are used, the results might misrepresent the overall performance and hence the conclusions could be potentially very misleading. Efficiency often depends on the combination of a number of interrelated input and output factors. Furthermore, in the day-to-day operation of airports one can usually observe substitution effects (e.g. where capital is substituted for labour, therefore improving labour productivity) and hence it is important to understand the overall performance of airports. In order to highlight the important weakness of partial performance indicators or in other words to illustrates the need for more sophisticated measures of efficiency measurement we have produced an example of own calculations based on data taken from the most recent ATRS study.

We have extracted the data of 30 international airports (including Oslo) from the ATRS (2009) data set and have computed a number of partial efficiency measures. The following three figures show the labour productivity of these 30 airports.

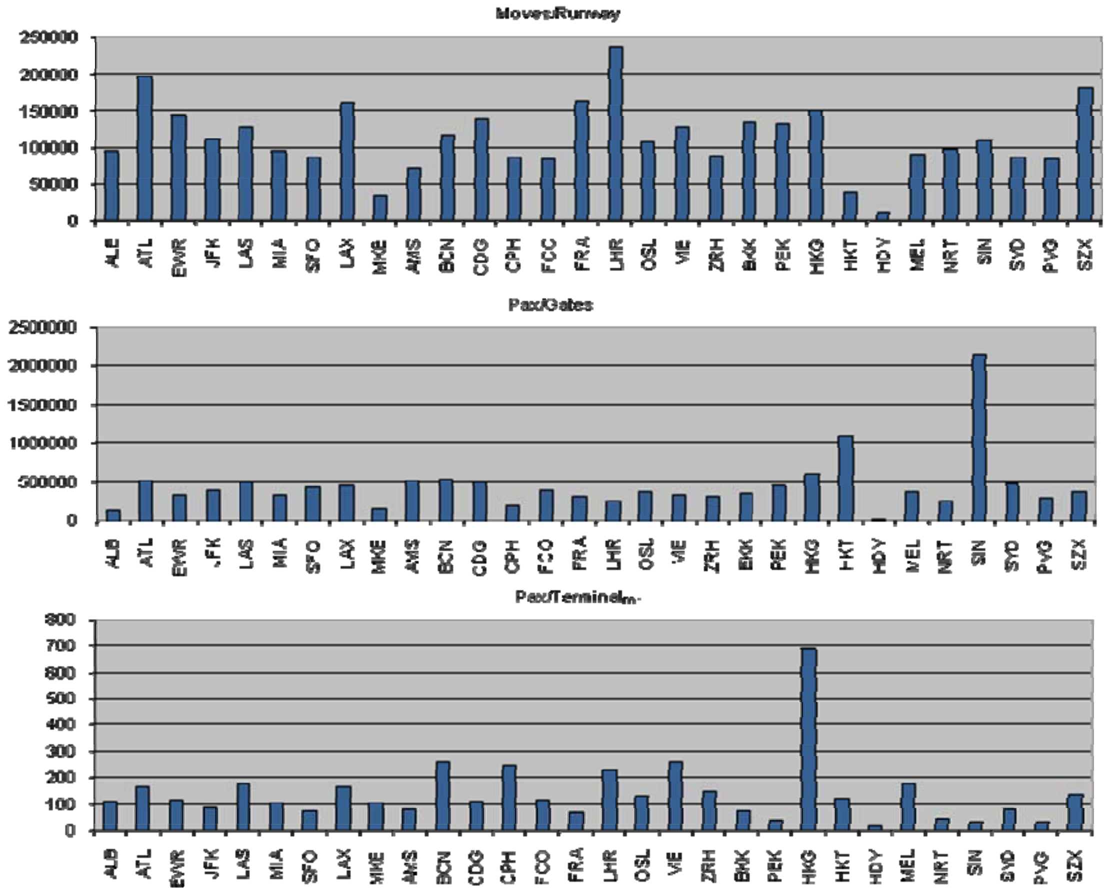
Figure 4.8: Labour productivity of our own exemplary 30 airports



Calculations based on data from ATRS (2009)

It becomes apparent that the North-American airports (Atlanta, EWR and JFK) are relatively more labour efficient than their international peers. However, even with regard to the single aspect of labour, it also becomes evident that there are differences in the relative performance depending on the chosen specific indicator. Atlanta, for example, is a top performer in passengers and overall aircraft movements per full time equivalent employee. In contrast, since Atlanta is less strong in terms of cargo movements, it is not in the top-performing group when the labour productivity is calculated as lifted cargo per full time equivalent. This phenomena becomes even more important when the second partial input factor, namely capital, is considered, as shown in the following three figures.

Figure 4.9: Capital productivity of our own exemplary 30 airports



Source: Own calculations based on data from ATRS (2009).

Particularly, if capital productivity is measured in passengers per gate but also in terms of passengers in relation to terminal size, the North-American airports are not in the best performers group of the analysed airports.

As a result, if one takes an overall view on these six partial performance indicators for the relevant 30 airports (as shown in the Figure below), it is more than difficult to establish a conclusion on which individual airport or which group of airports is performing best.

Table 4.10: Results of our own exemplary partial efficiency measurement results

PPM measure	**Top 3 airports in 2007**
Pax/FTE	JFK, ATL, EWR
Moves/FTE	ATL, EWR, JFK
Cargo/FTE	JFK, HKG, EWR (NRT very close)
Moves/Runway	LHR, ATL, SZX
Pax/Gates	SIN, HKT, HKG
Pax/Terminal m²	HGK, VIE, BCN

Source: Own calculations based on ATRS (2009) data.

From this simple example it becomes apparent that partial efficiency measures are of limited use and can potentially mislead and misrepresent the performance of an airport. Therefore, more recently most academic efficient studies have applied more sophisticated approaches such as Total Factor Productivity analysis, parametric methods such as the Corrected Ordinary Least Squares (COLS) analysis or the Stochastic Frontier Approach (SFA) and non-parametric methods such as Data Envelopment Approach (DEA). Their fundamental advantage is that they consider multiple inputs and outputs together to produce a single efficiency measure.

4.3.3 Previous applications to airports

As shown in table 4.11, most recent airport efficiency measurement studies have applied either a SFA or a DEA-type approach. Whenever a number of airports where analysed over a number of years, previous applications have preferred the SFA method or a DEA method combined with a Malmquist index. For an assessment of the performance of airports for a single point in time, DEA appears to be the preferred method. This is due to its fundamental advantage of not having to make strong assumptions on production/cost functions and cost minimising behaviour that SFA requires. In addition, DEA models can produce robust results with substantially smaller samples than SFA and without any information on the prices of the used inputs.

Table 4.11: Previous literature on airport efficient analysis

Study	Sample	Method
Gillen and Lall (1997)	23 US airports	DEA
Hooper and Hensher (1997)	6 Australian airports	TFP
Graham and Holvad (1997)	25 EU and 12 Austral. airports	DEA
Murillo-Melchor (1999)	33 Spanish airports	DEA/Malmquist
Jessop (1999)	32 international airports	DEA
Nyshadham and Rao (2000)	25 EU airports	TFP
Sarkis (2000)	44 US airports	DEA
Pels at al. (2001)	34 EU airports	DEA/TFP
Gillen and Law (2001)	22 US airports	DEA/Malmquist
Martin and Roman (2001)	37 Spanish airports	DEA
Abbott and Wu (2002)	12 Australian airports	DEA/Malmquist
Martin-Cejas (2002)	40 Spanish airports	TFP
Pacheco and Fernandes (2002)	33 Brazilian airports	DEA
Barzagan and Varsigh (2003)	45 US airports	DEA
Holvad and Graham (2003)	21 UK airports	DEA
Pels, et al. (2003)	33 EU airports, 1995-1997	DEA/SFA
Barros and Sampaio (2004)	13 Portuguese airports	DEA
Sarkis and Talluri (2004)	44 US airports	DEA
Yoshida (2004)	30 Japanese airports	TFP
Yoshida and Fujimoto (2004)	43 Japanese airports 2000	DEA
Hanaoka and Phomma (2004)	12 Thai airports	DEA
Kamp and Niemeier (2005)	17 EU airports	DEA/Malmquist
Vogel (2006)	35 EU airports	DEA
Vasigh and Gorjidooz (2006)	22 US and EU airports	TFP
Barros and Dieke (2007) Barros and Dierke (2008)	31 Italian airports 2001-2003	DEA + index
Fung et al. (2007)	25 Chinese Airp. 1995-2004	DEA/Malmquist
Barros (2008) Barros et al. (2010)	32 Argentinian airports 2003- 07	DEA
Oum et al. (2008)	109 Int. airports 2001-2004	SFA
ATRS (2009)	143 Int. airports 2007	TFP
Barros and Weber (2009)	27 UK airports, 2000 - 2005	DEA/Malmquist
Assaf (2010)	27 UK airports 2007	DEA
Lozano et al. (2009); Lozano et al (submitted); Lozano and Gutiérrez (submitted)	39 Spanish airports 2006- 2008	DEA/ Malmquist

Source: Own analysis.

The key findings of the above studies can be seen in two areas. Most of the studies, such as Barros et al. (2010), have identified best and worst performers within the pre-selected peers (comparison group). In terms of DEA studies, a number of authors have applied a two-stage approach. They have used the first stage efficiency scores as dependent variable in second-stage regressions to determine the determinants of the revealed (in)efficiency of the relevant airports. Such drivers include ownership and size of the individual airports but also degree of regulation and subsidies. As common for efficiency analysis of transport infrastructure (see for example Merkert et al. 2010) some of the reviewed airport studies have overcome the potential problem of biased results of any two-stage DEA, by applying a bootstrapping procedure that produces bias corrected results. It is widely agreed now that these bootstrapped DEA results would be appropriate to use as dependent variables in second stage regression models.

The second powerful key finding of some of the previous studies, such as Assaf (2010), is that they have revealed economies of scale for their analysed airports. This means that they have established whether some of the analysed airports are too big or too small (compared to their peers) in order to produce technically efficient.

In terms of the determined type of efficiency the previous literature is primarily focused on technical efficiency. Whether to use DEA or SFA varies by the taste of the author, because since recent improvements to both methods their results can be seen as equally robust.

In terms of inputs, previous applications have, generally, used physical inputs for DEA and cost data for SFA but some previous airport DEA’s have also used cost data. Although the specific inputs used in the previous efficiency analysis studies also varies by the taste of the author or data availability the four most commonly used inputs factors are:

- *Labour,*
- *Length and number of runways,*
- *Terminal size*
- *and Airport area.*

Almost all previous studies used the following output factors:

- *Passengers*
- *Cargo*
- *Aircraft movements*

Since DEA and SFA combine these output factors, it is not necessary to take assumptions that are required for partial measures such as WLUs or ATUs. Since nowadays airports produce more than aircraft movements, some of the previous studies reflected this by adding occasionally non-aeronautical revenue as a fourth output.

In sum, the most beneficial aspect of the more sophisticated methods is that they combine several inputs and outputs to produce a single overall efficiency measure.

To illustrate that argument, we have applied an input oriented DEA model to the 30 airports of the ATRS (2009) data set, which we have discussed above in terms of the weaknesses of partial efficiency measures. The following table shows the descriptive statistics of this simple data set and highlights the differences across the chosen 30 international airports in terms of the 4 input and 3 output factors.

Table 4.12: Descriptive statistics of our own exemplary DEA efficiency measurement results

	N	Mean	SD	Min	Max
Inputs					
FTE	30	2225.45	3306.02	137	17769
Runways	30	2.97	1.26	1	6
Terminal (m2)	30	380295.8	333549.4	7257	1382000
Gates	30	91.43	54.45	5	264
Outputs					
Pax	30	35353170	20333704	135679	89379287
Cargo (tonne)	30	1047561	983288.2	10142	3800000
Moves	30	335398.8	189653.6	11748	981402

Source: Own calculations based on data from ATRS (2009)

As shown in Table 4.13, the results of this our DEA model show that the airports that were high performers in one or two partial efficiency measures are not in the top-group when it comes to their overall performance.

Table 4.13: Results of our own exemplary DEA efficiency measurement results

Airport	CRS	CRScor	VRS	VRScor	CRS/VRS	CRS/NIRS
ALB	1	0.8453	1	0.8847	1	C
ATL	1	0.8436	1	0.8834	1	C
EWR	1	0.8704	1	0.8975	1	C
JFK	1	0.8451	1	0.8892	1	C
LAS	0.9432	0.8568	0.9530	0.8912	0.9897	D
MIA	0.7086	0.6277	0.7431	0.6898	0.9536	D
SFO	0.6967	0.6412	0.7006	0.6596	0.9944	D
LAX	0.9248	0.8283	0.9383	0.8695	0.9857	D
MKE	0.8913	0.7898	1	0.8966	0.8913	I
AMS	0.7734	0.6919	0.8202	0.7701	0.9429	D
BCN	1	0.8797	1	0.9109	1	C
CDG	0.8365	0.7452	0.8651	0.8053	0.9669	D
CPH	0.6453	0.5791	0.6526	0.6051	0.9888	I
FCO	0.6805	0.6366	0.6850	0.6517	0.9934	D
FRA	0.8637	0.7812	0.8654	0.8035	0.9981	I
LHR	1	0.8493	1	0.8854	1	C
OSL	0.7260	0.6590	0.8655	0.8069	0.8388	I
VIE	0.9477	0.8649	0.9759	0.9157	0.9711	I
ZRH	0.6843	0.6247	0.7042	0.6564	0.9717	I
BKK	0.7910	0.7094	0.8370	0.7783	0.9451	I
PEK	0.7973	0.7177	0.7990	0.7407	0.9978	I
HKG	1	0.8425	1	0.8832	1	C
HKT	1	0.8500	1	0.8831	1	C
HDY	0.2348	0.1970	1	0.8843	0.2348	I
MEL	0.9647	0.8550	1	0.8921	0.9647	I
NRT	0.8779	0.7814	0.9549	0.8887	0.9193	I
SIN	1	0.8380	1	0.8885	1	C
SYD	0.9295	0.8255	0.9961	0.9217	0.9331	I
PVG	0.5746	0.5148	0.5920	0.5468	0.9707	I
SZX	0.9382	0.8223	1	0.8842	0.9382	I

Source: Own calculations.

When we extract the important information from Table 4.13, and combine it with the findings of the partial efficiency measurement we can see that the airports with the highest overall efficiency are to some extent not the once that one would have expected after the first couple of partial efficiency measurements.

Table 4.14: Summary of the partial and overall efficiency measurement results

PPM measure	Top 3 airports in 2007
Pax/FTE	JFK, ATL, EWR
Moves/FTE	ATL, EWR, JFK
Cargo/FTE	JFK, HKG, EWR (NRT very close)
Moves/Runway	LHR, ATL, SZX
Pax/Gates	SIN, HKT, HKG
Pax/Terminal	HGK, VIE, BCN
Overall efficiency (TE VRS corr.)	SYD, VIE, BCN

Source: Own calculations

Our results suggest further that the North American airports are, in terms of economies of scale, operating at a more efficient size compared to, for example, Asian airports which have the potential to grow further and hence even increase their technical (overall) efficiency.

To sum up, the more sophisticated methods of DEA and SFA are powerful techniques that dominate the recent literature on efficiency measurement of airport. Based on our literature review and given the interesting results produced by our simple DEA model, we recommend anyone who is interested in the overall efficiency of particular airports or a group of airports to undertake either a DEA or a SFA type of analysis. Ideally one would additionally compute a number of partial efficiency measures, which can be useful for the interpretation of the DEA/SFA results.

From discussions with Avinor, we have established that data on key inputs (labour, length/number of runways, terminal size and airport area) but also on the key outputs (passengers, cargo and aircraft movements) would be available for all airports operated by Avinor. Since, the data appears to be most consistent and relatively easily available when measured in physical values (for example FTE for labour rather than staff costs) for a single fiscal year across the relevant airports it appears as most appropriate to use a two-stage DEA approach for the efficiency analysis.

4.3.4 Summary of the sophisticated measures and data availibility

From the preceding sections it appears that DEA is an appropriate method for assessing efficiency for Avinor. The main advantages of DEA over other methods and which are relevant for the assessment of Avinor are as follows:

- DEA is easy to grasp and understand for managers; the benchmark is other service providers providing the same type of services using the same types of inputs and, these other providers are observable and not derived from some assumed production function.
- DEA readily incorporates multiple inputs and outputs and, it does not require price data to calculate technical efficiency. This makes it especially suitable for analysing the efficiency of service production, where it is often difficult to assign prices to many of the outputs.
- It determines sources of inefficiency and efficiency levels and provides a means of decomposing economic (cost) efficiency into technical and allocative efficiency. Furthermore, technical efficiency is decomposed scale effects and non-scale effects.
- DEA identifies the “peers” for units (airports) that are not efficient. It thus provides a set of role models that the inefficient units can look to for way of improving its operations. This makes DEA a potential tool for benchmarking that other methods do not.
- DEA can be extended to study efficiency over time using the Malquist productivity index. Thus its advantages over other methods are maintained even when efficiency is being studied over time.

Like any assessment method, DEA too is based on a number of assumptions and hence has some weaknesses that one needs to acknowledge. The main ones are follows:

- DEA is a deterministic rather than a statistical approach. Its results would therefore be sensitive to measurement errors. However, recently it has been proven that applying DEA together with bootstrapping takes account of noise adequately.
- DEA only measures efficiency relative to best practice within a particular sample. Thus it is not meaningful to compare efficiency scores across samples or across different studies.
- DEA scores are sensitive to the number of inputs and outputs, and the sample size. Increasing the sample size will tend to reduce the average efficiency score because including more observations provides greater scope for DEA to find a comparison partner. Conversely, fewer observations relative to the number of inputs and outputs can inflate the efficiency scores. There are however ways of dealing with this problem. A rule of thumb is that the number of units in the sample should be at least three times greater than the sum of the number of outputs and inputs included in the analysis.

Despite its weaknesses, most of which can be corrected for, e.g. by applying the bootstrapping method, DEA is a useful tool for investigating the efficiency of government service providers such as Avinor. It is the potential benefits of DEA as compared to other approaches that must be recognised and explored to increase an understanding of the performance of Avinor and, if needed, identify ways of improving that performance.

Our recommendation for the method that should be used to assess the efficiency of Avinor is therefore DEA. The final DEA formulation to be used will depend on data availability. If for instance, only physical data on inputs is available, only technical efficiency can be measured. If price data is also available, both technical and allocative efficiency can be measured. Irrespective of the type of the data that is available, we recommend that: (1) DEA be conducted in two stages, where in the second stage the DEA efficiency scores are regressed on external factors such as ownership, regulation, weather conditions etc., to infer how these factors influence efficiency and, (2) DEA be conducted together with bootstrapping to certain confidence intervals for the efficiency scores derived and, (3) DEA's extension to the Malmquist Productivity Index (MPI) be used to study the developments in efficiency over time.

For a summary of findings and a discussion of data availability in practice, see Section 1.

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Web pages

www.avinor.no

MØREFORSKING MOLDE AS
Britvegen 4, NO-6411 Molde

Telefon +47 71 21 40 00
Telefaks +47 71 21 42 99

mfm@himolde.no
www.moreforsk.no

HØGSKOLEN I MOLDE
Postboks 2110, NO-6402 Molde

Telefon +47 71 21 40 00
Telefaks +47 71 21 41 00

post@himolde.no
www.himolde.no