Performance Evaluation of ANSPs with DEA.

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Contents

Introduction.

Chapter 1 introduces Air Traffic Management, its development through years and its most important institutions, as the International Civil Aviation Organisation, ICAO, or EUROCONTROL.

Chapter 2 focuses on Air Navigation Service Providers, ANSPs, which are national entities, who control air traffic in national boundaries.

Then in **Chapter 3** ANSPs' features are highlighted and described.

Chapter 4 and Chapter 5 deal about technical tools of the analysis. In **Chapter 4** a brief introduction of DEA is done, while in **Chapter 5**, ″R″ , the software used, is presented.

An overview on previous analysis on airports performance evaluations is done in **Chapter 6**, deserving special attention to the ones carried out with DEA.

The thesis ends with **Chapter 7** in which each step of the analysis is described and conclusions are highlighted.

Abstract

This thesis evaluates the performances of the Air National Services Providers using Data Envelopment Analysis. The analysis is carried out with the software R and it investigates advantages and limitations of DEA in benchmarking ANSPs. Our study deals, furthermore, with how *"'bad-inputs/outputs"'* and *"'non-discretionary inputs"'* have to be treated with DEA.
The study can be read as a guideline for future DEA analysis.

Chapter 1

ATM: Air Traffic Management.

ATM is a combination of services, functions and facilities defined as ”the aggregation of ground based and airborne functions required to ensure the safe and efficient movement of aircraft during all appropriate phases of operations”[1].

1.1 Development of ATM.

During the first years of aviation there was no air traffic management at all, as the air flow was so low that it was not needed. The ATM evolved gradually, driven by demand. After 17th December in 1903, when the Wright brothers invented and built the world’s first successful aircraft, the need for an operational watch over aircraft in flight prompted the institutions of air traffic control. There was a clear need to know where an individual aircraft was and to do it more efficiently the newly-invented wireless tool was used: this involved more cooperation between different specialists, who were involved in this field. The development of air navigation was particularly accelerated by World War I, characterised by its utilisation of military applications and shortly after the first airline was born: the Dutch carrier Koninklijke Luchtvaart Maatschappij (KLM) (1919). After that, important proof of the feasibility of long distance flight was given with the first transatlantic flight from Newfoundland to Ireland, and the commercial implications were quickly realized: airlines sprang up everywhere in the subsequent decades.

By the time of World War II, even if overall there were not many aircraft, some kind of control on air navigation was needed. Administrators decided that regulations and standardisation were required so within the Versailles Peace Treaty, the International Convention of Air Navigation was born. Nineteen nations signed this convention giving impetus to the development of general rules and tools for air traffic control such as air routes, controllers, advisory services, control towers, radars, etc.

In November 1944 the first meeting of the International Civil Aviation Organisation (ICAO) was held. Even today this body still manages all aeronautical spheres and establishes world standards. It is divided into ten regions managed by seven regional offices, which are responsible for the regulation and application of the local laws. The ten regions are the following: Africa, the Indian Ocean, Asia, the Caribbean, Europe, the North Atlantic, the Middle East, North America, the Pacific and South America.

1.2 EUROCONTROL.

In 1960 EUROCONTROL was established. The European Organisation of Air Navigation is made up of 39 Member States. The aim is to achieve safe, efficient and environmentally-friendly air raffic operations. It provides skills and technical expertise for aeronautics and flight across Europe and manages the flows of its participants so that the user demand does not overload the capacities offered. It also plays a pivotal role in Europe by working together with all aviation partners to deliver a Single European Sky.

1.3 ANSPs: Air National Service Providers.

Each European state is responsible for providing air traffic service as a public one and has the sovereignty over its air space, except in some case when states can delegate some of its territory to a neighbouring state.

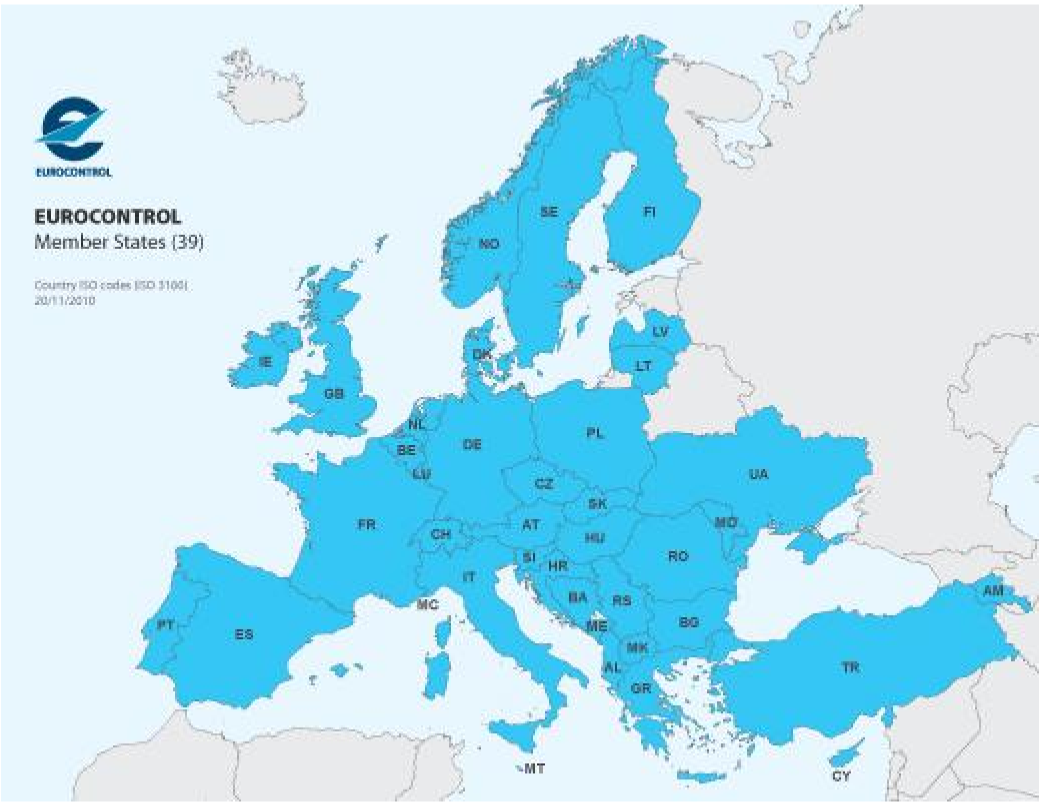

Figure 1.1: EUROCONTROL Member State

Chapter 2

ANSPs: Air National Service Providers.

2.1 What ANSPs are.

Each State has to provide a public air traffic service. In the earliest days of aviation, numerous states themselves financed air navigation services (ANS) but later refused to continue doing so; nowadays almost all EU member states have now set up corporate entities for this purpose. This behavior gave rise to the appearance of service providers who have become financially autonomous, primarily through levied user charges. These providers are called Air Navigation Providers (ANSPs) and, according to ICAO, they are controlled by independent authorities or entities.

We can describe three basic forms of ANS at national level:

- a government department;
- an autonomous body belonging to the public sector, but still remaining state property;
- a partly or fully privatised company.

In 1999 the Single European Sky was born. It was an European Commission initiative regarding the reform of air traffic management. It was adopted in early 2004 and it soon became clear that the Community policy and the intergovernmental cooperation were a good opportunity for further development of EU air navigation transport.

After that, while, traditionally, air navigations services were provided by government departments, almost all EU member states set up corporate entities for that purpose. Most of them are public owned, but some have been partly privatised. ANSPs enjoy a natural monopoly of the air traffic management of their area of responsibility, typically the area of the state.

National ANSPs do not always work within a linear and simple environment as the territory of states may be too small to allow efficient and cost-effective ATM, and as traffic flows may not be accommodated easily in this territorial organisation. In some cases a cross-border partnership has been pursued: for example Luxembourg had delegated the responsibility for most of its lower airspace to Belgium, while the upper airspace over the Benelux countries and over North Germany is managed through a joint facility set up by EUROCONTROL in Maastricht Upper Area Control centre (MUAC).

In table (2.1) there is the comparison between the status of NATS, the United Kingdom's ANSP and the status of NAVIAIR, Denmark's ANSP. As may be noted, NATS is one of the rare examples of a fully privatised ASNP, while NAVIAIR is 100% part of the State. For comparison the status of the Italian ANSP, ENAV is shown.

2.2 Coordination and Control of ANSPs.

The air traffic management is controlled by member states and the industry's technical experts, but with coordinated decisions, made with EUROCONTROL bodies. ANSPs are submitted to the Single Sky legislation signed by each member state. National authorities continue to play a major role, not only because some of them participate in the ANSPs activity, but mostly because this privatisation trend needs to have adequate monitoring structures.

NATS	NAVIAIR	ENAV
<u>Status (2011)</u> - Public Private Partnership as of 2011: 49% State owned; 51% private owned (42% by the Airline Group, 4% by BAA and 5% by UK NATS employees) - The Airline Group comprises 7 UK airlines: BA, Virgin Atlantic, BMI, Easy Jet, Thomas Cook, Thomson Airways and Monach Airlines	**<u>Status (2011)</u>** - Company owned by the state - 100% State-owned	**<u>Status (2011)</u>** - Joint-Stock Public Corporation as of 2001 under contract management - 100% State-owned by the Ministry of Economy
National Supervisory Authority UK CAA	National Supervisory Authority Danish CAA	National Supervisory Authority Italian Civil Aviation Authority ENAC
Body responsabile for *<u>Safety Regulation</u>* UK CAA, Safety Regulation Group *<u>Airspace Regulations</u>* UK CAA, Directorate of Airspace Policy *<u>Economic Regulation</u>* UK CAA, Economic Regulation Group which sets charges through a formula linked to the Retail Price Index	Body responsabile for *<u>Safety Regulation</u>* Civil Aviation Administration *<u>Airspace Regulations</u>* Civil Aviation Administration *<u>Economic Regulation</u>* Civil Aviation Administration	Body responsabile for *<u>Safety Regulation</u>* ENAC and Ministry of Transport *<u>Airspace Regulations</u>* ENAC *<u>Economic Regulation</u>* Ministry of Transport and ENAC review annually ANS charges in cooperation with Ministry of Economy and Ministry of Defense.

Figure 2.1: Status of NATS, NAVIAIR and NATS.

Therefore, member states are expected to set up independent supervisory authorities on ANSPs' work. These safeguards are required also to avoid decisions being affected by conflicts of interest, due to operational functions being carried out within the same organisation. Further to this, European legislation provides for a systematic performance review as an instrument to identify best practices and to organise their dissemination. This is carried by EUROCONTROL's Performance Review Commission (PRC) which, over the years, has published a series of very valuable annual and topical reports. These Performance Reviews establish a set of rules by which ANSPs in Europe are certified. These requirements include technical and operational competences, financial strength, organisational structures, human resources, liability and insurance cover, reporting systems and processes for safety and quality management.

2.2.1 Review Reports as a basis of this study.

To define ANSPs characteristics and to understand which of them would be more interesting in our analysis, two reports particularly have been taken into account: the Performance Review Report 2010 (PRR) [11] and the ATM Cost-Effectiveness 2009 (ACE) [10].

The PRR gives positive or negative feedback in the following fields.

Safety. The safety performance review deals with assessing and measuring the status of the ANS safety system with respect to its effectiveness. It records the number of accidents and the most severe incidents, the quantity and the quality of safety management and, even, the just culture environment itself within which safety management operates. The Just Culture is defined as [3] "a culture in which front line operators or others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience or training, but where gross negligence, wilful violations and destructive are not tolerated".

Environment. The environment review deals with the responsibility that the aviation industry has to minimise its global and local impact on the environment. ANSPs are described for their efforts in improving fuel efficiency and reducing aviation emission. Furthermore it covers also local air quality and noise at major airports.

Capacity. This section looks at the capacity plan of the ANSP and how it is able to answers to changes in traffic trends.

Cost Efficiency. This Key Performance Indicator focuses on ATM/CNS costs incurred by ANSPs.

ACE 2009 presents factual data and analysis on cost-effectiveness and productivity for 37 Air Navigation Service Providers (ANSPs) in Europe for the year 2009, including high-level trend analysis for the years 2005-2009 [10].

These reports describe exhaustively the way of working of each ANSP looking at one at a time without any comparisons between them. It is possible to make a realistic comparison of the ANSPs, noting where they are working well and where not. This way of judgment by comparison is called Benchmarking.

Chapter 3

Benchmarking ANSPs.

The Benchmark of ANSPs is considered a valid tool to control those entities. Let us make an overview on the ANSPs which will form part of our analysis.

In total, 37 ANSPs reported 2009 data in compliance with the requirement of Decision No. 88 of the Permanent Commission of EUROCONTROL. In addition to the EUROCONTROL Member States, the en-route ANSPs of two Baltic States (Estonia and Latvia) provided data on a voluntary basis for inclusion in the analysis. After the accession to EUROCONTROL, the sample of 37 ANSPs includes for the first time a full information disclosure from the Armenian ANSP, ARMATS.

The data processing, analysis and reports are conducted with the assistance of representatives from participating ANS, airspace users, regulatory authorities and the Performance Review Unit (PRU). After collecting data, in order to ensure comparability among ANSPs and quality of analysis, the information is judged by the PRU.

3.1 Data.

The collected data by ACE for each ANSP contain the following elements.

Gate-to-gate ANS revenues (not adjusted by over/under recoveries) (in € M):
En-route ANS revenues
Terminal ANS revenues
Gate-to-gate ANS costs (in € M):
ATM/CNS provision costs
MET costs
EUROCONTROL Agency costs
Payment to national authorities and irrecoverable VAT
Gate-to-gate ATM/CNS costs (in € M):
En-route ATM/CNS costs
Terminal ATM/CNS costs
Gate-to-gate ANS staff:
ATCOs in OPS
ACC ATCOs
APPs + TWRs ATCOs
NBV of gate-to-gate fixed assets (in € M)
Gate-to-gate capex (in € M)
Outputs (in M)
Distance controlled (km)
Total flight-hours controlled
ACC flight-hours controlled
IFR airport movements controlled
IFR flights controlled
Gate-to-gate ATFM delays > 15 min. ('000 min.)

Figure 3.1: Data for European ANS

The term *Gate-to-gate* refers to the fact that the ANSP's control on whatever flight starts when it leaves the departing airport and finishes when the flight lands at the arriving airport.

Further terms include:

- *en-route*, "during the flight";

- *terminal*, "in to the actions under the airport control".

Regarding the difference between *ANS* and *ATM/CNS*, the first acronym refers to Air National Service, while the second one describes Air Traffic Management and Centre NOTAM Service[4].

The data that are considered in the European ANS system data are:

- **revenues**;
- **provision cost**;
- **ANS staff**;
- **delays**.

Total revenues in 2009 were 7 712 million euro. Almost all "en-route revenues" come from the collection of charges, while the proportion is lower for terminal revenue, as additional income may directly come from airport operators much of which is subsequently recovered from airspace users and passengers.

Total cost in 2009 was 8 627 million euro and it represents costs from:

- *ATM/CNS provision cost*;
- *aeronautical Meteorological costs*;
- *payments for regulatory and supervisory services*;
- *payments to governmental authorities*.

The total **ANSPs Staff** in 2009 were 57 500 persons. In the overall system of employers we may distinguish:

- *Air traffic Controllers* working on operational duty (ATCOs in OPS), who are the ones directly involved in operations;
- and *Technical support staff* for maintenance and administration staff, who are not directly related to the active control of traffic.

Minutes of Delays. A flight is considered as delayed once 15 minutes have passed since its scheduled arrival. Delays are divided into two categories:

- *en-route delays* which involved delays arising from:
  - ATFM delays;
  - flight efficiency;
  - access and utilisation of the airspace.
- *terminal delays*.

When capacity is not able to respond adequately to demand delay occurs.

3.2 Exogenous and Endogenous factors.

The following features should be considered.

One of the most important elements that should be highlighted, also to understand the importance of a good and equal benchmarking method, is the heterogeneity among our sample of ANSPs. The 37 ANSPs operate in very diverse environments across Europe and are of different sizes. Five ANSPs (AENA, DSNA, NATS, DFS and ENAV) bear 60% of the total ATM/CNS provision cost because of their capacity to gain traffic compared to the whole European system. To better understand the reason for the greater share of money on the total amount, earned by those 5 ANSPs, the share of traffic must be taken into account: for the 5 largest ANSPs this stands at 54%.

So, data will be influenced by each particular characteristic of the ANSP, which should be distigueshed between:

- Exogenous factors
- Endogenous factors.

3.2.1 Exogenous factors

Those are the elements which are not under the direct control of the ASNP and that cannot be modified. They differ from ANSP to ANSP and exhibit different characteristics.

ANSPs have to work differently to manage their own exogenous factors and we have to consider them to achieve fair benchmarking. They have been classified into two main areas.

Legal and socio-economic conditions, such as:

- exchange and inflation rates;
- cost of living and market wage rates;
- working hours;
- retirement age.

Operational conditions, for example:

- size of the ANSP;
- traffic complexity;
- spatial and temporal traffic variables;
- weather.

Additionally, also the institutional and government arrangements in a given country are important because they define the way in which an ANS is regulated, the ANSP ownership and control structure and the civil/military rules.

In our analysis just the traffic pattern will be considered.

3.2.2 Endogenous factors.

These elements are the ones under the direct control of the ANSP, which belong to the different particular framework for each one of the 37 ANSPs.

With the endogenous factors ANSPs manage the exogenous factors, and exhibit their way of working, which at the end will show their efficiency. ANSPs always have the aim to optimise their endogenous factors to reach the optimal situation. They comprise the following fields:

organisational factors,

- the internal organisation structures;
- relationship with customers;
- human resources;
- the degree to which assets and activities are retained in-house;

managerial and financial aspects, which means the quality of management and financial accounting considerations;

operational and technical set up, i.e. the operational structure and flexibility.

3.3 Our choice.

Of the whole list of data available to compute the following analysis, just some of them have been selected. Here below are presented the elements which we will meet during our study.

Total IFR flights controlled by the ASNP. This measure refers to the number of flight IFR which pass under direct control of the ANSP. IFR means Instrument Flight Rules, that is an Acronym for properly equipped aircraft that are also allowed to fly under bad weather conditions following instrument flight rules.The main source for all

ANSPs' data is CFMU, despite EANS, LGS, Oro Navigacija for which ACE is the source.

Composite Flights hour. In ACE 2001 the concept of "composite flight-hours" was introduced to reflect the fact that the service provided by ANSPs is "gate-to-gate" and that the difference in the boundaries used by different ANSPs between terminal and en-route ANS could distort the picture obtained if they were considered individually. It finally combines the two separate output measure for en-route and terminal ANS. "Composite gate-to-gate flight-hours" were defined as "en-route flight-hours" plus IFR airport movements weighted by a factor that reflected the relative (monetary) importance of terminal and en-route costs in the cost base. This average weighting factor is based on the total monetary value of the outputs over the period 2002-2009 and amounts to 0.26. The composite flight-hours are therefore defined as:

En-route flight-hours +(0.26× ***airport movements*)**

ATM/CNS provision costs. They are the total controllable ANSP costs, including both En-route and terminal category in real term. The ATM/CNS provision cost largely covers the total cost and form the basis for the analysis of ATM cost effectiveness for most of the reports. The total amount of "provision costs" is given the following categories of costs:

- **(63%) staff costs**:
  - employment costs for ATCOs in OPS;
  - employment cost for all other staff;
- **(18%) non staff operating costs**
  - rentals, energy, insurance, outsourced mainteinance;
- **capital related costs,** such as:

- (11%) depreciation;
- (6%) the cost of capital;
- (2%) exceptional items.

ATCOs in OPS. An Air Traffic Control Officer who is participating in an activity that is either directly related to the control of traffic or is a necessary requirement for an ATCO to be able to control traffic. Such activities include manning a position, refresher training and supervising on-the-job trainee controllers, but do not include participating in special projects, teaching at a training academy, or providing instruction in a simulator.

En-route delays. EUROCONTROL defines them as: ”Delays caused by regulation based on traffic volume which has a reference location classified as AS (Airspace) or SP (Special Point)” or as ”ATFM delay caused by regulations applied by the CFMU (Central Flow Management Unit) at the request of the FMP to protect en-route ATC sectors from overload”[12].

Delays are one of the main elements responsible for increasing costs, as from them arise problems linked with airport capacity, problematic interrelations with others flights, dissatisfaction of customers and so on.

Complexity. The complexity index embodies a general exogenous factor, which is computed on a systematic basis for each day of the year. Complexity is defined as ”interactions”. Interaction arises when two aircraft are in the same place at the same time, and is the result of two indeces:

- **structural index.**
  This index is given by the sum of those three elements: horizontal, vertical and speed interactions.
- **traffic index.**
  Traffic density indicator is a measure of the potential number of

interactions between aircraft and is defined as the total duration of all interactions (in minutes) per flight-hour controlled in a given volume of airspace.

The definition of complexity is the following:

$$\textbf{\textit{Complexity score}} = \textbf{\textit{Traffic density}} \times \textbf{\textit{Structural index.}}$$

A high score of complexity means that the zone is "‘crowded"’ and, consequently, its management needs more resources and strengths than other zones with a lower score of complexity.

In conclusion, it should be noted that our following study is more focused on how DEA, a particular benchmarking method, can be used to benchmark ANSPs; thus so we are concentrating more on technical features, i.e. how to treat different type of data. This includes the differences in treating in a diverse way the same group of data and other elements that will be shown. This means that the group of data used is not sufficient wide for an equal comparison, as we do not consider, for example, the cost of living among states, which will be relevant since we are considering the ATM/CNS provision cost, which includes also ATCOs in OPS wages.

Chapter 4

DEA.

DEA is the acronym for Data Envelopment Analysis a non-parametric method to evaluate efficiency among a sample of producers.
DEA was formulated for the first time by A. Charnes, W. Cooper e E. Rhodes (1978) and it is becoming an important management tool.

4.1 Parametric and non-Parametric Techniques.

A *parametric method* (Deterministic Frontier Analysis - DFA; Stochastic Frontier Analysis - SFA) draws a production function, underlying "a priori" the weights for each element, accounted for the analysis. It is clear that by choosing a parametric method the most important features are already chosen among the whole sample and, in doing so, favours the producers who are "'strong"' in this area. On the other hand, the other producers whose strengths lie elsewhere are disadvantaged.

A *non-parametric method* (Data Envelopment Analysis - DEA; Free Disposal Hull - FDH) does not work with an already existing production function or efficiency frontier, but allows an evaluation among similar producers thanks to linear programming techniques, which do not need data about different production settings and, moreover, do not need the specification of weights for each element accounted for in the analysis.

Both techniques allow us to work with multiple inputs and outputs.

The non parametric technique is consequently more objective and is advantageous because it has a very flexible production structure, but, on the other hand, the parametric ones allow a better separation of noise and inefficiency.

4.2 DMUs, Input and Output

DEA deals with a sample of similar units, which are called *DMUs, Decision making Units*. These DMUs can be whatever we want, their definition is generic and flexible: hospitals, Air Force wings, universities, cities, courts, business firms, and others, including the performance of countries, regions, etc.

A DEA analysis defines two sets of DMU features: the *input* group and the *output* group. Input and output data have to be comparable among the different DMUs; for that reason, similar entities are requested. One DMU is seen as a black box, which absorbs inputs and returns outputs, so inputs can be seen as the resources used by the entity to produce outputs. Furthermore DMUs work in parallel and their flows are completely independent, besides the fact that they autonomously decide how to deal with their inputs.

When we have just one input and one output the *efficiency* measure is defined as the ratio of output, to input. DEA defines the efficiency measure in a multiple input-output system. In any case the value of efficiency is always in the interval $(0;1)$, where 0 means that the DMU is completely inefficient, whilst 1 means that the DMU is working in a best practice. Traditionally the optimal DMUs lie on an ideal frontier, which is called *operative* or *efficiency frontier*, all the rest of DMUs are in the area behind it and aim to reach it.

Once the input and output sets have been drawn up the efficiency evaluation of a given DMU is calculated by comparison of its technology set with all the possible technology sets arising from the linear combination of the observed production sets.

In practice, for each DMU, DEA is looking for its best technology set, weighting more heavily the features for which DMU is stronger and then, with this most convenient assumption for the given DMU, comparing it with all the others. This process is made for each DMU and gives a relative efficiency index. At least the efficiency measure is an equal measure, where no one DMU has been disadvantaged by "‘a priori"’ choice: each DMU has been been evaluated concerning its best technological set.

DEA gives us richer results than a simple value of efficiency for each DMU, so that strengths and weaknesses can be known. At the end, DEA gives the following results:

- for each DMU,
  - a *relative efficiency measure*,
    which is defined as follows: "‘A DMU is to be rated as fully (100%) efficient on the basis of available evidence if and only if the performances of other DMUs does not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs"’[13].
  - *virtual weights*.
    They show the importance of each flow (input or output) in the final efficiency measure and are defined as the multiplication of the flow for its weight.
- for the inefficient DMUs,
  - *peers*.
    They are the optimal DMUs that dominate the given inefficient one. The optimal entities lie on the efficient frontier and the weaker DMU does not, but aims to.
  - *targets*.
    Defines which flows have to be increased or decreased to make the DMU efficient.

4.3 Different method (VRS, etc..).

Given the assumptions made about the technology set, there are different DEA models.
The principal assumption that can be made are the following:

- *free disposability*: it is possible to produce less with more;
- *convexity*: any weighted average of feasible production plans is feasible as well;
- *Y-return to scale*: production can be scaled with any of a given set of factors;
- *additivity:* the sum of any two feasible production plans is feasible as well.

From these assumptions arise six classical DEA models:

1. **FDH** - *Free disposability hull, no convexity assumption*;
2. **VRS** - *Variable return to scale, convexity and free disposability*;
3. **DRS** - *Decreasing return to scale, convexity, down-scaling and free disposability*;
4. **IRS** - *Increasing return to scale, convexity and free disposability*;
5. **CRS** - *Constant return to scale, convexity and free disposability*;
6. **FRH** - *Free replicability hull*.

According to the choice made, the operative frontier will have a different form: for some methods it will be wider, allowing more DMUs to reach the total efficiency and for some methods it will be stricter.

Returns to scale refers to increasing or decreasing efficiency based on size. For example, a manufacturer can achieve certain economies of scale by producing a thousand circuit boards at a time rather than one at a time, it might be only 100 times as hard as producing one at a time. This is an example of increasing returns to scale, **IRS**. On the other hand, the manufacturer might find it more than a trillion times as difficult to produce a trillion circuit boards at a time though because of storage problems and limits on the worldwide copper supply. This range of production illustrates decreasing returns to scale **DRS**. Combining the two extreme ranges would necessitate variable returns to scale **VRS**. Constant Returns to Scale **CRS** means that the producers are able to linearly scale the inputs and outputs without increasing or decreasing efficiency. The assumption of CRS may be valid over limited ranges but its use must be justified. As an aside, CRS tends to lower the efficiency scores while VRS tends to raise efficiency scores. In benchmarking applications it is always important to discuss which assumption to make "a priori", because it may have a huge impact on the value of efficiencies. The choice of the model results in a different efficiency frontier, some times wider, that allows more DMU to reach the efficiency frontier, some times narrower.

Normally firms prefer the FDH model, to the VRS one, because they all have higher efficiency scores in this. While CRS is the worst alternative for most firms.

4.4 Input-Output Oriented.

A DEA study can be conducted using the notion of efficiency measured as the largest possible proportional contraction of all inputs or the largest possible proportional expansion of all outputs. We will call *Input oriented* the first efficiency direction and the second one *Output oriented*.

4.5 DEA's Advantages and Limitations.

A few of the characteristics that make it powerful are:

- DEA can handle multiple input and multiple output models;

- it does not require an assumption of a functional form relating inputs to outputs;
- DMUs are directly compared with a peer or combination of peers;
- inputs and outputs can have very different unit of measurement.

The same characteristics that make DEA a powerful tool can also create problems. An analyst should keep these limitations in mind when choosing whether or not to use DEA:

- since DEA is an extreme point technique, noise such as measurement error can cause significant problems. DEA is good at estimating *relative efficiency* of a DMU but it converges very slowly to *absolute efficiency*. In other words, it can tell you how well you are doing compared to your peers but not compared to a "'theoretical maximum"';
- since DEA is a non-parametric technique, statistical hypothesis tests are difficult and are the focus of ongoing research;
- since a standard formulation of DEA creates a separate linear program for each DMU, large problems can be computationally intensive.

The exponential increasing of the adoption of DEA in Benchmarking in the first years of 2000, was due to the fact that, before it, Benchmarking was always considered an unfair science. Before DEA it was not possible to compare similar entities without giving a "'a priori"' direction to the analysis. It means that comparing big and small producers was almost impossible, because their features were so different that the benchmarking encountered a trade-off between advantage characteristics of the small producer or the contrary. Once DEA was developed, this comparison between different entities became possible because there was not an "'a priori"' direction and small producers could be analysed on an equal basis with big ones.

Chapter 5

R.

R is a language and environment for statistical computing and graphics. It was originally created by Ross and Robert Ihaka and Robert Gentleman at the University of Auckland in the early 90's.

R can be considered as a different implementation of S, which is also a high level language and an environment for data analysis and graphics, developed at Bell Laboratories by John Chambers and colleagues. John M. Chambers, the creator, in 1998, received the ACM Software System Award where S was cited as "'The S system, which has forever altered how people analyze, visualize, and manipulate data"'.

5.1 Advantages of using R.

R is available as Free Software released under the terms of the Free Software Foundation's GNU General Public License in source code form. This means:

- freely available without a fee;
- free to see how it is written;
- free to reuse the code under the same terms.

The software is open source, meaning people can pick it up for free and make their own changes to the code. Such flexibility has inspired statistically-minded people of all fields to get behind R and make it a real success story.

Furthermore its performance is comparable with other commercial software, it has flexible and easy programming methods. Moreover it provides a wide variety of statistical and graphical techniques, and is highly extensible. For this reason, R is used in different fields and its increasing adoption at universities for everything from biology to economics should be noted.

The main advantage of R is the community on CRAN (over 2461 packages and counting). Nothing will compare with this in the near future, not even a commercial application like matlab. With regard to how many people use R, it has be noted, from a number of people interviewed, including those who work most closely with the software, that the estimated R population is at 250 000. Intel Capital has placed the number of R users at 1 million and Revolution kicks the estimate up to 2 million. Such disparity often accompanies open-source projects, where it is difficult to estimate how many people the software reaches.

5.2 The R environment.

R is an integrated suite of software facilities for data manipulation, calculation and graphical display.
It includes:

- an effective data handling and storage facility;
- a suite of operators for calculations on arrays, in particular matrices;
- a large, coherent, integrated collection of intermediate tools for data analysis;
- graphical facilities for data analysis and display either on-screen or on hardcopy;
- and a well-developed, simple and effective programming language which includes conditionals, loops, user-defined recursive functions

and input and output facilities.

5.3 The package "‘Benchmarking"’.

The use of R in the following analysis is focussed on how it has to be used to solve DEA problems.

To compute the following analysis the package "‘Benchmarking"’ [14] has been used. The package contains methods to support frontier analysis and it covers Data Envelopment Analysis (DEA). DEA is supported under different technology assumptions and using different efficiency measures.

Peers and slacks are available, partial price information can be included, and optimal cost, revenue and profit can be calculated. Evaluation of mergers is also supported. Methods for graphing the technology sets are also included. The package also supports comparative methods based on Stochastic Frontier Analyses (SFA). In general, the methods can be used to solve not only standard models, but also many other model variants. The package complements the book, Bogetoft and Otto, Benchmarking with DEA, SFA, and R, Springer-Verlag, 2011, but can of course also be used as a stand-alone package.

5.3.1 Different Technology assumption.

First of all it gives us the possibility to compute the efficiencies of some DMUs under different technology assumption.

"‘Benchmarking"’ gives the user six different models to deal with:

- **crs**: original constant return to scale model;
- **drs**: decreasing return to scale;
- **irs**: increasing return to scale;
- **vrs**: varying return to scale;
- **fdh**: free disposability hull;

- **frh**: free replicability hull.

In our analysis the VRS model has been chosen .

5.3.2 Different efficiency measurement.

The value of efficiencies follows the direction that we are imposing on our analysis.

The directional efficiency can be:

- restricted to input, with **ORIENTATION="in"**;
- restricted to outputs, with **ORIENTATION="out"**;
- or both inputs and output directions, with **ORIENTATION="in-out"**, which does not discriminate the importance of possible increase of output or decrease of input.

5.4 Other R functions used.

The function **lambda** returns the weight of the peers for each firm. Each row is the lambdas for the firm corresponding to that row. A column shows for a given firm how other firms are compared to this firm.

The function **peers** finds for each firm its peers, while **get.number.peers** finds for each peer the number of times this peer appears as a peer, and **get.which.peers** determines for one or more peers the DMUs they appear as peers for.

```
> ritardi <- read.table(file='C:/Users/....txt')
```

A table filled with data is imported.

```
> attach(ritardi)
```

attach() says to R that functions have to be apply to ritardi's dataframe.

```
> ritinput<-ritardi[,1]
> reciproco<-ritardi[,2]
> kgrande<-ritardi[,3]
> provcost<-ritardi[,4]
> atco<-ritardi[,5]
> totalflights<-ritardi[,6]
> cfh<-ritardi[,7]
```

Each column is named.

```
> input<-matrix(c(provcost,atco),ncol=2)
```

An input matrix is made by the union of two vectors.

```
> output<-matrix(c(kgrande,totalflights,cfh),ncol=3)
```

An output matrix is made by the junction of 3 columns.

```
> e_vrs<-dea(input,output,RTS='vrs', ORIENTATION='in')
```

dea: we are saying to R that it has to compute a DEA on the two matrix of input and output depicted above.
RTS: the argument RTS defines the DEA returns to scale assumption, which, in this case is "**vrs**", e.g. variable returns to scale, convexity and free disposability.
ORIENTATION: the argument stresses the direction of the efficiency measure, which might be "**in**" input efficiency, "**out**" output efficiency, "**graph**" and graph efficiency. An additional option is "**in-out**".For use with **DIRECT**, an additional option is "in-out".

```
> eff(e_vrs)
```

Efficiency is calculated on data given in e_vrs object.

```
 [1] 1.0000000 0.6204779 1.0000000 0.6099234 0.7333552 0.4258574 1.0000000
 [8] 0.6918450 0.9823039 1.0000000 1.0000000 1.0000000 1.0000000 0.8751227
[15] 0.7043980 0.7468608 0.7170211 1.0000000 0.8326043 1.0000000 0.6154652
[22] 0.6454580 0.7002896 0.8343297 1.0000000 1.0000000 0.9382410 1.0000000
[29] 0.8376983 0.6392609 0.5953306 0.8440091 0.6998612 0.5714914 0.7248163
[36] 0.9864266 0.7326511
```

List of the efficiency scores for each DMUs.

Figure 5.1: Example of R code to calculate the efficiency values in Test one.

Chapter 6

Already existing DEA analysis in airports field.

6.1 Benchmarking.

The performance benchmarking, as a management tool, was pioneered by Robert C. Camp at the Xerox Corporation in the late 1970's, where he used this tool to identify shortcomings of that company's photocopier production and distribution. He used benchmarking to identify several key practices from the photocopier industry to improve the company's photocopier business. The performance measurement and benchmarking techniques have all evolved significantly since that time, but the principal aim for any benchmark is always the same: to identify performance gaps and to find practices that will help close that gap.

6.2 Airport Benchmarking.

Airport benchmarking studies began appearing in the literature in the early 1990's with the study of Tolofari, Ashford, and Caves, "'The cost of air services fragmentation"'[15], in which airports operated by the British Airport Authority were compared against each other.

In the space of a very few years (beginning of 2000) an exponential growth of air traffic has been seen. Air transportation has reached a wider public of customers: it is not addressed only to an higher revenues class, but it's now available to everyone. Air traffic is fast changing and it is increasing in many directions.
Consequently airport management has to deal with congestion of infrastructure, safety, sustainability, airport and air traffic privatization and commercialization, alliances between airlines and the continued rise of low cost carriers. The airport's work is then controlled by some specific Key Performance Indicators (KPI), which show if one airport is a good-working one, that it is able to handle all of these difficulties, or it is an under-performing one.

Benchmarking within the airport industry has been accepted only during the last 15-20 years. This is because, at first, the airport sector was handled by government and identifying outputs and inputs was difficult because of its diversity. When airports began to be privatized, a wide range of business tools was required to control its development, which includes also benchmarking.
Financial and physical inputs and outputs were then designed.

As inputs, original benchmarking considers, generally speaking, the capital input and the capacity of airport , while the outputs of an airport were assessed in three ways: in terms of aircraft or air transportation movements, passengers or freight. These data allow the measurement of cost efficiency, revenue generation and staff productivity.
At the same time, complexity of the traffic and airport size have to be included. Recently elements such emissions, wastes, energy used, noise, i.e. environmental aspects were added into the analysis.

6.2.1 Different Benchmarking Techniques in Literature.

Airports are using different benchmarking techniques. In 2000, a survey of the 200 largest airports in the world was undertaken by the UK Open University and Loughborough University to know how airports were measuring their performances. Nowadays the TRL and the Air Transport research Society publish once a year a review of indicators for a sample of airports from different regions of the world.

The following table (6.1) shows the principal benchmarking analysis made on different samples of airports. As can be seen the first one was carried out in the 90′ on a UK sample of airports.

The article **"'Developing measures of airport productivity and performance: an application of data envelopment analysis"'** [2] it is interesting mainly for two reasons:

- it is the first article which deals with developing measurements of airport productivity and performance and is the first one which talks about DEA;

- airports at that time were still under government control, but they were considered developed enough to stand alone and operate without government support.

So the article stands perfectly in the middle between public and private management.

Moreover it wants to determine how much variation in airport performance can be attributed to managerial decision-making and initiatives and what are the important decisions or strategies within that portion of airport performance that an airport manager can affect. This study could afterwards help the management of airports under private control or could stress the economical potentiality of this field.

"'The performance of BAA before and after privatization: a DEA study"' [5] investigates which is the most feasible method to evaluate airport performances and the DEA method is considered one of the best ones. This is because DEA answers well to applications where outputs are not easily or clearly defined and, moreover, can incorporate multiple outputs and inputs without getting into problems of aggregation.

Author(s)	Date of Publication	Methodology	Airports covered
Tolofari Ashfors Caves	1990	Parametric TFP	BAA UK
Prices surveillance authority	1993	Index number TFP	6 Australian
Gillen Lall	1997	DEA	US 23
Hooper Hensher	1997	Index number TFP	6 Australian
Graham Holvad	1997	DEA	25 european and 6 australian
Parker	1999	DEA	BAA and 16 UK
Adler Berechman	2001	DEA	26 major
Pels Nijkamp Tietveld	2000	DEA	33 european
Jessop	1999	DEA / Multiattr. assessment	44 US
Martin Roman	2001	DEA	37 spanish
Martin Cejas	2001	Parametric TFP	40 spanish
Fernandes Pacheco	2002	DEA	33 Brazilian
Bazargan Vasigh	2002	DEA	45 US
ARTS	2002	Parametric TFP	76 major

Table 6.1: Benchmarking Analysis on Airports.

The article deals with a data set composed of information from 21 of the 30 airports in the United States for the period 1989-1993. In that paper, a differentiation between terminal and movements services was made, then for each one of them inputs and outputs were founded.

Concerning the terminal services, as inputs we find: number of runways, number of gates, terminal area, number of employees, number of baggage, collection belts number of public parking spots, while, as output we have: number of passengers and pounds of cargo. Movements have four inputs; airport area, number of runways, runway area and number of employees and two outputs: air carrier movements and commuter movements.

DEA is working then under an output oriented model.

"'An application of DEA to measure the efficiency of Spanish airports prior to privatization"' [6].
Besides the authors' idea that some benchmarking tools, as productivity ratios, are not clear enough to understand overall performance, they apply DEA to analyze efficiency of Spanish airports.

The article starts with considerations on the privatization process started in 1970 in USA, then moving across ocean, to Europe, fostering good services and new improvements. The article, in an era where airports are subject to more competitive pressures, answers the following question "Are private airports more efficient than their public counterparts?".

DEA is chosen among the numerous numbers of benchmarking methods because it does not impose a parametric structure on the data, it provides a good approach to measuring total factor productivity and its information requirements are less restrictive. In the paper, an output orientation was used. The outputs chosen were: air traffic movements, number of passengers and number of tons of cargo transported in each airport. Input variables were labor, capital and materials. After that they compare the results from a CRS and VRS analysis on the same data set and draw the following conclusions.

"'Management style and airport performance in Brazil"' [7] uses data envelopment analysis techniques to investigate the impact of changes in managerial style, from public to a private ownership, on airport performance between 1998 and 2001.

The outputs used were three financial and two operational: operating revenues, commercial revenues, other revenues, passengers embarked plus disembarked, cargo embarked plus disembarked. Concerning inputs, the paper includes: payroll, including direct and indirect benefits, operating and other expenses, average number of employees.

The conclusion of the paper is that despite a decline in operational performance, financial performance improved.

"“Size versus efficiency: a case study of US commercial airports"” [8]. This study of the 45 US airports was conducted using the DEA method, already proofed as an optimal tool for such an analysis. The paper also studies the nature of the sample of airports concerned: small, medium or large and if, and eventually how, their size could influence their efficiencies.

For input measures the following were used: operating expenses, non-operating expenses, number of runways and number of gates. 6 different output data groups were used: number of passengers, number of carrier operations, number of other operation, aeronautical revenue, non aeronautical revenue and percentage of on time operations. To carry out the study, a CCR model was used.

This test shows that the small airports consistently outperform the large hubs based on their relative efficiency scores.

As we can see from Table 6.1, different methods have been used in benchmarking, including the Data Envelopment Analysis (DEA).

Through the articles summarized previously it may be seen that DEA is one of the most attractive techniques because of it requires less data and because it gives us a good framework on different performances, the analysis of best practice and the potential improvements.

Generally, input are:

- *structural elements*: number of runways and number of employees;

- or *financial element*: costs and expenses.

While there is a general behavior in choosing as output:

- the number of passengers;
- or the aircraft movements.

Recently there hase been some debate on the adoption of "'regulatory benchmarking"', but there is a lack of consensus on what can be considered the optimal benchmark; this is because of the choice of suitable input/output and the difficulties in taking into account the operating environment and exogenous factors.

It is clear that airport's benchmark has been growing over these last years, however the difficulty arising from the diversity of inputs and outputs still remains.

6.3 NERA's Report.

The report made by NERA, **"'Cost Benchmarking of Air Navigation Service Providers: a Stochastic Frontier Analysis"'** [9] presents the results of an econometric analysis of the costs of air navigation service providers (ANSPs) in Europe.

Even if the subject of the analysis is the same as our, the ANSPs, the analysis made by NERA differs over 2 principal elements:

- first, to compute the analysis they used a different method from DEA: the Stochastic Frontier Analysis (SFA)
- secondly the NERA report focuses on a methodological framework for the study of ATM cost efficiency, while our aim is to compute a general and all-inclusive efficiency.

6.3.1 Why using SFA rather than DEA?

The Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are examples of, respectively, parametric and non-parametric techniques.

Parametric techniques (which include SFA, Corrected Ordinary Least Squares (COLS) and others) are based on regression analysis. They assume a particular specification of the relationship between a firm's costs and a set of cost drivers. Econometric analysis is then used to estimate the parameters of that relationship. Having estimated a cost function, inefficiency is one of the factors that can explain the differences between the observed level of costs for a particular firm and the level of cost predicted by the estimated cost function.

In contrast, DEA is a non-parametric mathematical programming technique widely used in the operations research and management science literature. DEA establishes an efficiency frontier, taking account of all relevant variables. Each firm is then assigned an efficiency score based on its proximity to the estimated efficiency frontier.

The first highlights which are the factors in the firm which affect most the efficiency, but will not indicate if we are competing well or not in generally. The second method stresses how good is that firm, compared to the others, but it does not give any information about noise or errors.

Lastly, the efficient cost frontier estimated will be different depending on which method will be used between the two. Under either approach, the efficiency of a company is then measured by its distance from the estimated frontier.

6.3.2 Different inputs/outputs.

Concerning the groups of inputs and outputs, our analysis has assumed different set of elements on which compute the efficiency. Clearly the two aims are different: NERA's report aims to investigate on the efficiency cost, while this present thesis aims to show an overview on the good or bad performance of the ANSPs.

In NERA's case these are as:

- **inputs:**

    1. *the labour price*, measured as the hourly Air Traffic controller (ATCO) employment costs and by the unit employment costs for non-ATCO staff;
    2. *capital input price*, measured as the ratio of capital-related costs to an aggregated capital input measure;
    3. *non-staff operating input price*, which captures all the remaining costs not included in either labour or capital;
    4. *network size*, in terms of the size of airspace controlled by the ANSP;
    5. *traffic variability*, which concerns complexity score, adjusted density, structural complexity;

- **output:**

    1. *number of composite flight hours controlled*.

However, the model estimation is affected by several problems, including the too small size of the sample, multicollinearity and, the fact that potential exogenous factors are not identified.

Chapter 7

Evaluation of performances of ANSPs with DEA.

7.1 Object and Data of the analysis.

The analysis focuses on 37 Air National Services Providers, working under EUROCONTROL, and it uses data given by ACE 2009 [10] and PRR 2010 [11].

The study evaluates their performances by comparison, giving an efficiency value for each of them. Optimal ANSPs gain an efficiency value equal to 1, while under performing ANSPs have a value inferior to 1.

As it is possible to see, in literature there are different studies which calculate ANSPs efficiency with DEA. Among them, a general distinction may be made between studies investigating technical efficiency and studies investigating economical efficiency. Our study is also interested in carrying out a technical efficiency, which gives an overview of the ”well-working” ANSPs and the under performing ones.

To understand the positive working level of ANSPs the following data, which in the analysis are called "‘flows"’, have been chosen and grouped, as below, into two classes:

- **inputs**, resources used;

- **outputs**, things produced.

The characteristics describing ANSPs have been introduced in section (3.1).

7.1.1 Input.

Inputs are resources on which entities are built, as they use them to produce their output. The way ANSPs work with them defines their efficiency. Generally speaking, an entity will be more efficient when, compared to another one which is producing the same level of outputs, uses less input.

Here below there are the features that best describe ANSPs.

1. **ATM/CNS provision costs.**
   They represent the monetary funds for each ANSP.

2. **ATCOs in OPS.**
   This data refers to human resources.

3. **Complexity.**
   It shows the difficulty that ANSP has to handle.
   The complexity, as will be highlighted in section (7.6), is a "'strange"' input and, for this reason, it has not to be treated as the other inputs.
   It is called *Non discretionary Input*.

7.1.2 Output.

Outputs are what ANSPs produce. A high-performing ANSP, with a given level of input, is capable of producing more outputs than the others. We can say that ANSP's aim is to have a big output related to small input.

The following characteristics have been chosen to describe what, traditionally, ANSPs produce.

1. **Total IFR flights controlled by the ASNP.**
   It describes the quantity of traffic the ANSP is able to manage.

2. **Total flights**.
   They are different from "‘complexity"’, as they are real data showing the number of flights which have been handled by the ANSP. On the opposite the "‘complexity"’ is a given value which describes theoretically the difficulty in managing the traffic.

3. **Composite Flights hour.**
   This index describes the quantity of traffic managed by the ANSP considering both ANSP areas: the "‘en-route"’ and the "‘terminal"’ one. It is complementary to the previous one.

4. **En-route delays.**
   This refers to the delays produced by an under-performing management.
   As it can be seen, delays are something that ANSPs produce. However, this kind of output doesn’t have to be as large as possible. For this reason it is called *"‘Bad Output"’* and has to be treated in a different way.

7.2 Approach in estimating the efficiency.

Efficiency studies have usually focused on the input rather than the output side. One possible reason is that greater control is available over input variables. For example, airport administrations have only a limited influence on the growth of outputs such as the number of passengers or quantity of cargo processed annually. Passenger and cargo demand depends on a series of factors such as regional economic development, and prices, income, service levels that are harder to measure in quantitative terms and are beyond the airport managers’ control. It is different in the case of inputs, where some control is possible over the variables used.

Because airports of different sizes are involved, the input-oriented approach was adopted for a **variable returns** to scale (”vrs”) model.

This study has been made in different stages which means that different analysis have been made.

This approach allows us to:

- understand how the introduction of a new data influences the results compared to the previous analysis;
- focus on the treatment of particular elements. Data with a diverse nature, like *Non Discretionary input* or *Bad Output*, could be analysed more thoroughly;
- make more than one efficiency analysis so that it allows us to obtain a more complete overview on the good performances of the ANSPs.

In each step the analysis passed through the following sections:

- the *Data used*, in which the flows considered are shown and how they are shared between input and output;
- *Meaning of the analysis*, where the aim of the analysis is specified;
- *Final picture*. Optimal and under-performing ANSPs are now highlighted and, moreover, peers units are depicted;
- *Plots and advanced informations*.

7.3 Test One.

7.3.1 Data used.

In the first step we consider 4 flows:

1. **ATM/CNS provision costs**;
2. **ATCOs in OPS**;
3. **Total IFR flights controlled by the ANSP**;
4. **composite flight hours**.

We divide them into

- **2 inputs**:
  1. *ATM/CNS provision costs*;
  2. *ATCOs in OPS*.
- **2 outputs**:
  1. *total IFR flights controlled by the ANSP*;
  2. *composite flight hours*.

The technology is **"'vrs"'** and an **"'input orientated measure of efficiency"'** is used.

7.3.2 Meaning of the analysis.

The analysis shows the ability of the ANSPs in managing resources as money and employers compared to the the number of flights controlled.

Indeed it does not allow us to see a real overview on ANSPs because we do not include any of the exogenous factors such as the weight of the traffic or of the cost of living, which differ from country to country and affect wages. Moreover, we do not stress bad features of the ANSP as, for example, the delays. For that, the efficiency value can be realistic only if we consider ANSPs when they work under the same exogenous hypothesis.

7.3.3 Final Picture.

The following estimations under the assumption of a **"'vrs"'** technology and an **"'input orientated efficiency measure"'** are calculated. Column 1 in table (7.1) shows all the 37 ANSPs with the correspondent score of efficiency.

Number of ANSPs with efficiency equal to 1 are 8.
Mean efficiency = 0.763.

Efficiency range	N° of ANSPs	Percentage
$0.4 \leq E < 0.5$	1	2.7
$0.5 \leq E < 0.6$	4	10.8
$0.6 \leq E < 0.7$	9	24.3
$0.7 \leq E < 0.8$	10	27.0
$0.8 \leq E < 0.9$	3	8.1
$0.9 \leq E < 1.0$	2	5.4
$E = 1.0$	8	21.6

Table 7.1: Summary of Test one.

Excellent.

The final efficiency values show that 8 ANSPs are excellent, so it means that their efficiency is 1. They stay on the efficient frontier and they do not need to improve because, as a consequence, they are already optimal.

1. ARMATS, Armenia;
2. DFS, Germany;
3. DHMI, Turkey;
4. DSNA, France;
5. EANS, Estonia;
6. MoldATSA, Moldavia;
7. MUAC;
8. NATS, United Kingdom.

Under-Performing.

Indeed, Belgocontrol clearly appears as the worst one, with only 0.258 of efficiency. Although, also Skyguide, BULATSA, Oro navigacija e ROMATSA have a low efficiency score.

Peer Units.

Looking at the peer units we can see that the ANSPs with more DMUs ″aiming″ at them are:

- MUAC, which is a peer unit 28 times.
  We note that MUAC is such an optimal ANSP because of its particular nature. It has no a concrete section with buildings or tools, it just relies on the German and Belgian structures. It is clear therefore how its provision cost and ATCOs are very low and it thus has a high efficiency score.

- EANS, which is a peer unit 27 times.
  EANS is one of the smallest European ANSPs with costs contributing 0,1% of the EU29 "′gate-to-gate ATM/CNS provision costs"′ in 2009 [11]. Furthermore EANS′ traffic complexity levels are very low.

- NATS, is a peer unit for other two ANSP: ENAV and Aena.

Plot and advanced information.

At the end of the first estimate, three different plots have been drawn to show the situation graphically.

Figure (7.1) shows how much quantity of inputs ANSPs use. "′ATM/CNS provision costs"′ and "′ATCOs in OPS"′ are, respectively, in abscissa and in ordinates.

In figure (7.2), indeed, there is the number of "′total IFR flights controlled"′, while in the ordinates there are the "′composite flights hour"′, thus the relation between the quantity of output used for each ANSP is evident.

From these plots it is also possible to draw some conclusions. Focusing, for example, on DSNA, France (12) and Aena, Spain (1) ANSPs we can see that both have high value of input, but it is also clear that Aena is producing so much less output that its efficiency will be clearly inferior than DSNA. Numerous comparisons and evaluations can be made, but

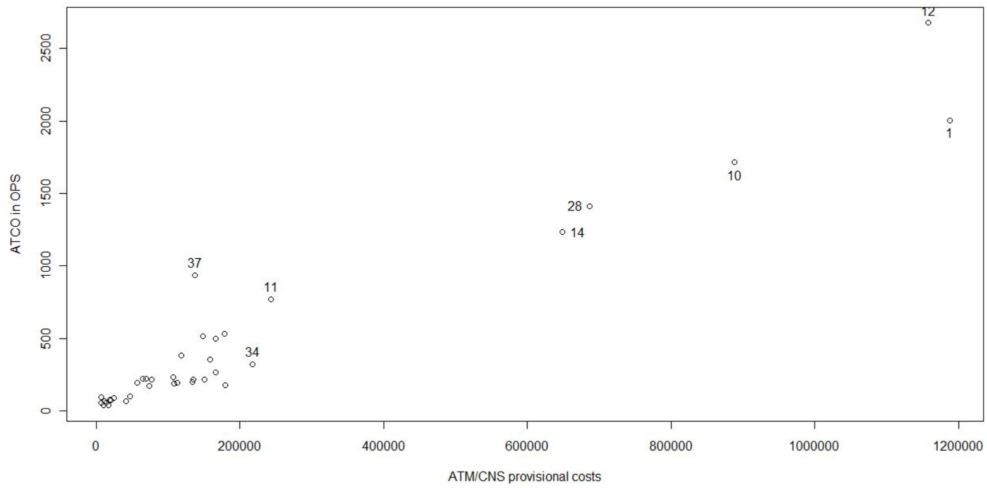

Figure 7.1: Inputs of ANSPs.

it would involve enormous work and a waste of time. For that reason benchmarking methods and software are used.

From the graphs, (7.1) and (7.2), the following may also be noted:

- comparing the two graphs, it is clear that in the first one there is a high concentration of ANSPs in the bottom left section, while in the output graph there is a more equal distribution. This difference is at the base of the efficiency measure. Among the group of ANSPs using low level of input, the ones producing more will gain higher efficiency values;

- secondly, the two graphs stress the correlation between the two inputs and between the two outputs.

Graph (7.3) shows the efficiency density function. It clearly highlights that there is a low concentration of ANSPs with an efficiency score less than 0.6 and that there are mainly two groups with a high ANSPs' level: the first one with an efficiency around 0.65 – 0.75, and the second one with an efficiency equal to 1.

Another possibility is to plot the function *"'eladder"'*: it calculates how the efficiency for a DMU changes when the most influential peer is removed

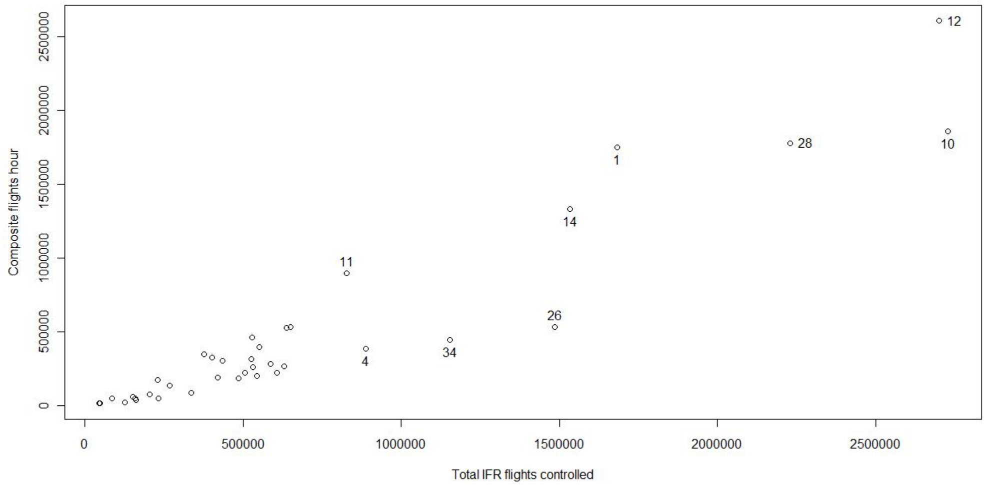

Figure 7.2: Outputs of ANSPs.

sequentially one at a time. Somewhere in the sequence, the firm becomes efficient and is in itself removed from the set of DMUs. The eladder function for Aena ANSP has been plotted.

We are focusing on Aena mainly because it is part of the 5 biggest ANSPs in Europe, which are DSNA (France), DFS (Geramany), NATS (United Kingdom), ENAV (Italy), but, at the same time, it has the lowest efficiency score among them. In particular DSNA, DFS and NATS are optimal, while ENAV and Aena are not.

7.4 Test Two.

7.4.1 Data used.

In the second step we've added the:
En-route delays data.

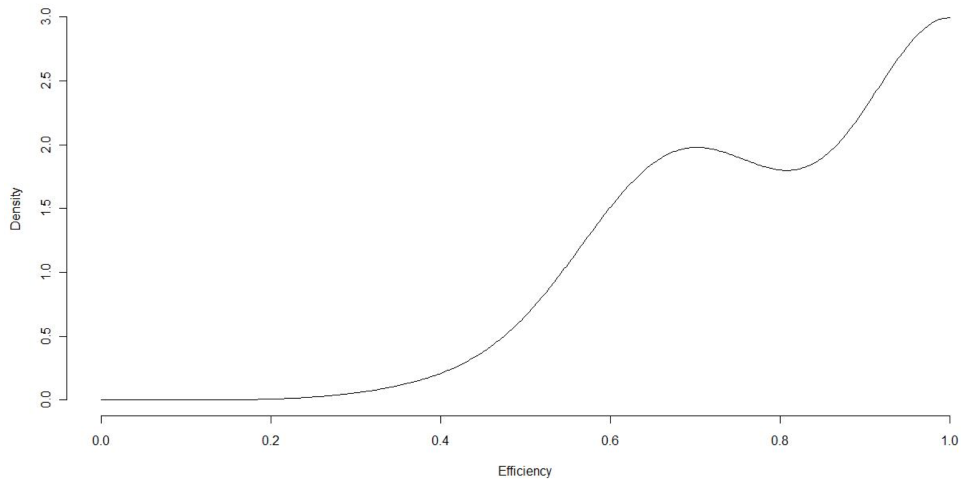

Figure 7.3: Density of Efficiency in Test One.

Undesirable output.

Delays are considered negative features in the management of an ANSP. The aim is to reduce them as much as possible; however, at the same time, "'delays"' are considered as outputs because they are a consequence of how the resources are used.
In a DEA analysis, where, considering the same input level, output has to be as big as possible to reach a better efficiency, an output such as "'delays"' causes some problems.
These kinds of outputs are called **Undesirable Output**.

Another typical example of a bad output is pollution, which, also in this case, contrasts the implicit assumption at DEA's base. The increasing of outputs are carefully considered: this issue does not work, of course, for the pollution.

In literature [16], to solve this problem there are *direct* and *indirect* approaches, respectively, if we are using data in themselves or if we are modifying them.

The approaches for a **direct resolution** are:

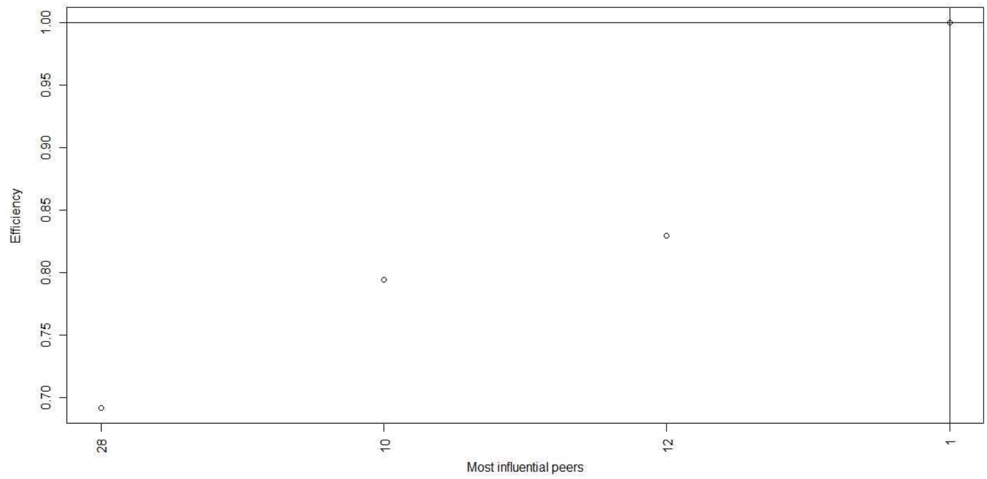

Figure 7.4: Eladder Function for Aena.

BoI: considering the Undesirable Outputs as input.
This happens because, as was shown before, they behave as inputs making my system more efficient as smaller as they are;

KO: subtracting the Undesirable Output from a sufficiently big number K. In this case my Undesirable Output will remain an output;

RO: considering the reciprocal number of my undesirable value: also in this case it is still considered an output.

Using one approach rather than another one, depends on the model we are considering, since each of them gives its own result. As we will see afterwards, the results, obtained by using each of the three different approaches, do not differ a lot from each other.

Coming back to our analysis, the flows used in the second step are divided as follows.

- **Inputs:**

1. *ATM/CNS provision costs*;
2. *ATCOs in OPS*.

- **Outputs:**

1. *total IFR flights controlled by the ANSP*;
2. *composite flight hours*;
3. *en-route delays*.

The **En route delays** are treated with all three methods, so in two calculations they are considered as outputs and, in the last one, as input.

Zeros in Data.

One particular feature has to be considered more than the others: M-NAV (Malta), BULATSA (Bulgaria), MoldATSA (Moldavia), EANS (Estonia), IAA (Ireland), ARMATS (Armenia), ROMATSA (Romania), LGS (Latvia), Oro navigacija (Lithuania) have a total amount of minutes of delays equal to zero.

Even if it seems unrealistic, it is possible that an "'En-route delays"' value equals zero. To prove this, it can be seen that those zeros were recorded in areas with low traffic, all regarding East Europe.

It follows that the majority of en-route ATFM delays are concentrated in only a comparatively small number of ANSPs which affects in a negative way the entire European network. The most "'delayed"' ANSPs are Skyguide (Switzerland), DCAC (Cyprus), HCAA (Greece), Austro Control (Austria), PANSA (Poland), Aena (Spain) and DFS (Germany). These seven providers represent 80% of the total amount of delays, made up of the whole sample of the 37 ANSPs. UK, Italy, Czech Republic and Portugal, for instance, continue the improvements made in previous years and maintain a constant good level of performance in terms of delay.

In DEA analysis a zero in data needs to be treated with caution and the strategy we have to follow depends on its nature and to how we are considering it. In our case we assume that the zero does not represent a missing data, but it represents a true quantity. It is then to a unit's advantage to include the input in the assessment.

Afterwards, it is important to underline that we are using data equal to zero only when we are considering the undesirable output as input. The efficiency scores obtained are in accordance to the ones computed with the other two strategies. In (RO) approach, the reciprocal value of en-route delays for the ANSPs which have the problematic 0 value was assumed equal to 2, so we can assume that we have treated the zero correctly.

It is interesting to note that, among the ANSPs with the value of "'en-route delays"' equal to 0, not all of these ANSPs reach the efficiency frontier. Comparing, for example, BULATSA to OroNavigacija, in the first step they have both low efficiency $(0,5)$. However only BULATSA takes advantage of the new output, while the second one remains at the same level.

The ANSPs with en-route delays equal to 0 that became optimal are:

1. BULATSA;
2. IAA ;
3. LGS.

While the followings ones were already optimal:

1. ARMATS;
2. EANS;
3. MoldATSA.

It follows that a value equal to zero is really "heavy" in the analysis, besides the fact it has been compared to values equal to 1309 minutes, the en route delays of AENA.

7.4.2 Meaning of the analysis.

The "'En route delays"' are the total minutes of delays caused by a situation such as a delay in take off dues to an already full capacity of the landing airport or the airspace or, simply, due to whatever malfunctions (strikes, few controlers at work and so on). Weather conditions influence also, as we could see in 2010 when the volcanic cloud paralyzed European air traffic.

Comparing the quantity of delays over the years there is an upward trend for the following ANSPs: Aena (Spain), DFS (Germany) and DSNA (France), while NATS (UK), ENAV (Italy), LPS (Slovak Republic) e NAV Portugal (Portugal) have low average values.

7.4.3 Final Picture.

Excellent.

The optimal ANSPs in all the three analysis are the followings:

1. IAA;
2. DHMI;
3. DFS;
4. MoldATSA;
5. LGS;
6. EANS;
7. DSNA;
8. ARMATS;
9. NATS;
10. MUAC;

11. BULATSA.

Some ANSPs, indeed, become optimal only in test 2a and test 2c, they are:

- ENAV;
- Hungaro Control;
- NAV Portugal;
- SMATSA;

Under-performing.

The following ANSPs have the worst efficiency values in all three tests:

1. LPS:
2. Austro Control;
3. Oro navigacija:
4. Skyguide;
5. Belgocontrol.

Efficiencies in relation to the strategy used towards Undesirable Output.

The undesirable output are considered with 3 strategies:

1. their own reciprocal number is considered an output (RO);
2. they are subtracted to a sufficient big number K and treated as an output (KO);
3. the original values is considered an input (BoI, Bad-output considered Input).

The technology is ″vrs″ and an ″input orientated efficiency measure″ is used.

Test 2a.

BoI approach.

Number of firms with efficiency equal to 1 are 15.

Mean efficiency: 0.848.

Efficiency range	N° of ANSPs	Percentage
$0.4 \leq E < 0.5$	1	2.7
$0.5 \leq E < 0.6$	2	5.4
$0.6 \leq E < 0.7$	6	16.2
$0.7 \leq E < 0.8$	5	13.5
$0.8 \leq E < 0.9$	4	10.8
$0.9 \leq E < 1.0$	4	10.8
$E = 1.0$	15	40.5

Table 7.2: Summary of Test 2a.

Test 2b.

RO approach.

Number of firms with efficiency equal to 1 are 11.

Mean efficiency: 0.796.

Efficiency range	N° of ANSPs	Percentage
$0.4 \leq E < 0.5$	1	2.7
$0.5 \leq E < 0.6$	2	5.4
$0.6 \leq E < 0.7$	10	27.0
$0.7 \leq E < 0.8$	7	18.9
$0.8 \leq E < 0.9$	4	10.8
$0.9 \leq E < 1.0$	2	5.4
$E = 1.0$	11	29.7

Table 7.3: Summary of Test 2b.

Test 2c.

KO approach.

Number of firms with efficiency equal to 1 are 15.

Mean efficiency: 0.843.

Efficiency range	N° of ANSPs	Percentage
$0.4 \leq E < 0.5$	1	2.7
$0.5 \leq E < 0.6$	2	5.4
$0.6 \leq E < 0.7$	6	16.2
$0.7 \leq E < 0.8$	6	16.2
$0.8 \leq E < 0.9$	3	8.1
$0.9 \leq E < 1.0$	4	10.8
$E = 1.0$	15	40.5

Table 7.4: Summary of Test 2c.

Out of 37 groups of 3 efficiency values, each of them given by a different treatment of bad outputs, we have:

- 26 terns, which remain the same even if bad outputs are treated differently;

- 7 situations where the efficiencies, derived from approach (BoI), are higher than the ones from approaches (KO) and (RO). In 5 of this 7 cases (KO) values are higher than (RO) and in the latter two values (KO) and (RO) are equal.

- 4 cases where (BoI) and (KO) have equal values higher than (RO). These 4 cases are interesting because in all of them the (BoI) and (KO) state the efficiency equal to 1, while (RO) does not allow the following ANSPs to reach the efficiency frontier:

    1. Hungaro Control;

    2. NAV Portugal;

    3. SMATSA.

We may note that approaches (BoI) and (KO) allow more ANSP to be optimal (15 ANSPs), indeed (RO) is more selective (11 ANSPs reach the efficient frontier), i.e. more difficult to reach the technological frontier because it is narrower.

HungaroControl (Hungary) and NAVIAIR (Denmark) take much more advantage in using approach (BoI) than the others, they have these efficiency increases: from 0.717 to 1.000; from 0.639 to 0.927, respectively.

At the same time the ASNPs, which remain with a low efficiency score no matter which kind of approach we are using, are the followings:

1. AustroControl;
2. Belgocontrol;
3. LPS;
4. Oro navigacija;
5. Skyguide.

Comparison with the first step.

If we look at the first table of efficiency and we compare our present efficiency values with it, we can note the following: the efficiency never decreases: the whole scores or remain or increase.

This behavior could be expected because, adding inputs/outputs to our data, we are giving more choices to ANSPs in choosing between the elements where to put the heavier weight.
We have:

- 20 efficiency values which remain the same as the first step;
- 17 which change.
  In this latter group of values it should be noted that the whole three efficiency values rarely differ from the one computed in the first step. Usually, the score given by the (RO) strategy remains equal to the first step's value.

In this second test, we have more ANSPs lying on the efficient frontier. The new entries are:

1. LGS;
2. IAA;
3. BULATSA.

Those ANSPs enter in the efficiency frontier no matter which strategy we have chosen to treat bad output, while the following ANSPs become optimal just in (BoI) and (KO) approaches.

They are:

1. ENAV;
2. Hungaro Control;
3. NAV Portugal;
4. SMATSA.

Concerning ENAV, in the previous section it was noted that among the 5 biggest ANSPs only ENAV and Aena were not optimal. Considering the new data, also ENAV becomes optimal, while Aena does not change its efficiency.

Indeed, focusing on the ANSPs which are still not optimal but which take advantage thanks to the new output, there are:

- SMATSA (2 minutes of delay);
- NAV Portugal (8 minutes of delay);
- Belgocontrol (from an efficiency value equal to 0.24 to one equal to 0.42);
- ROMATSA (delays equal to 0);
- HungaroControl (15 minutes of delays);
- ENAV (17 minutes of delays).

	Provision costs	ATCOs	total IFR movements	composite flight hours	en route delays
Provision costs	1				
ATCOs	0,96	1			
total IFR movements	0,9	0,87	1		
composite flight hours	0,96	0,97	0,94	1	
en route delays	0,63	0,56	0,63	0,58	1

Figure 7.5: Correaltion Indexes.

7.5 Test Three.

7.5.1 Data Used.

Here we are handling 5 flows:

1. the provision costs;
2. the ATCOs;
3. the total IFR movements;
4. the composite flights hour;
5. the en-route delays.

One more step may be made considering the correlation between data.

The analysis will consider only non-correlated data excluding part of the original flows. Afterwards, a comparison between efficiency values computed on correlated and non-correlated data will be made giving us the opportunity to understand if:

- a high correlation between data leads to some particularities;
- and how much weight in the analysis the inclusion of correlated data can have.

The correlation index between each couple of variables is summarized below.

We may see that the couple of variables that are highly correlated are:

- for the input:

    1. the provision cost;
    2. and the "ATCOs";

- for the output:

    1. the composite flight hours;
    2. and the total IFR movements.

As a result of this, the following analysis will compute the efficiency only on 3 flows divided as follows.

- **Input:**

    1. ATM/CNS provision costs;

- **Outputs:**

    1. composite flight hours;
    2. en-route delays.

The en-route delays are counted in the analysis as their reciprocal number.

7.5.2 Meaning of the analysis.

We wish to investigate the influence of correlated variables. The aim of this section is to understand if considering both the two variables with a high correlation index is useful.

Moreover, because a considered selection of inputs and outputs is at the base of a good selective DEA analysis, an investigation has been carried out on which inputs and outputs have to be excluded based on a reasonable idea.

7.5.3 Final Picture.

The technology is vrs and input orientated efficiency.
Number of firms with efficiency equal to 1 are 7.
Mean efficiency: 0.711.

Efficiency range	N° of ANSPs	Percentage
$0.3 \leq E < 0.4$	4	10.8
$0.4 \leq E < 0.5$	2	5.4
$0.5 \leq E < 0.6$	5	13.5
$0.6 \leq E < 0.7$	6	16.2
$0.7 \leq E < 0.8$	9	24.3
$0.8 \leq E < 0.9$	3	8.1
$0.9 \leq E < 1.0$	1	2.7
$E = 1.0$	7	18.9

Table 7.5: Summary of Test Three.

Excellent.

This analysis allows the following ANSPs to reach the efficient frontier:

1. ARMATS;
2. DHMI;
3. DSNA;
4. EANS;
5. IAA;
6. MUAC;
7. NATS.

Under-Performing.

The ANSPs with low score of efficiency are:

1. Oro Navigacija;
2. Slovenia Control;
3. LPS;
4. LVNL;
5. Belgocontrol.

Comparison with the previous tests.

The final picture shows a score of efficiencies which differ greatly from the one obtained including correlated variables. The comparison between the results of this test and of the second test, considering bad output as their reciprocal number, leads to this conclusion.

Generally speaking it can be noted that, excluding the ”total movements” from outputs and the ”ATCOs in OPS” from inputs, the efficiency values are lower and there are less ANSPs on the efficiency frontier.

Among the 11 optimal ANSPs in 2b analysis:

- 7 remain on the efficient frontier.
  This is the case of ARMATS, DHMI, DSNA, EANS, IAA, MUAC, NATS;
- the other 4 receive a lower efficiency score.
  This is the case of BULATSA, DFS, LGS, MoldATSA.

No one ANSP takes advantage in using this set of input and output.

Many ANSPs become weaker. Among them the following ones are the most disadvantaged:

- Slovenia Control, from 0.7248 to 0.3766;

- Nata Albania from 0.938 to 0.49.

On 37 ANSPs, 17 efficiency values do not change at all.

Influences of the selection of inputs and outputs.

"Composite Flights hour" and "Provisional costs" are chosen versus "Total Movements" and "ATCOs in OPS" since they are considered more significant, this because:

- "Composite Flights hour" embodies in its value the "Total Movement"

- and "Provisional Costs" also comprises the employees' wages.

To understand better what is happening under DEA and how much influence the choice to exclude some flows has, an ANSP that in this test is no more optimal has been studied. We focus our attention on which are its peer units.

DFS ANSP has been focused (Germany - 10) because, in all tests, this is the only one which is not on the efficiency frontier.

Weights for DFS in the "non-correlation" analysis show that it has as peer units the following two: DSNA (France) and NATS (United Kingdom).

Afterwards, looking at data it is possible to understand the following things:

- DFS is the ANSP that controls the biggest number of "total movements". DSNA and NATS follow immediately.
  The inclusion of "Total movements" makes it a peer unit.

- To understand which is the flow that makes DFS no more optimal, thus weaker than DSNA and NATS the remaining flows have been looked at: ″Composite Flights Hour″, ″Provision Cost″ and ″Enroute delays″. Thus is possible to see that, while concerning ″Composite Flights hour″ and ″ATCOs in OPS″ it stays between DSNA and NATS; DFS is inefficient at managing delays.

From this example is possible to see that, though the inclusion of correlated variable is good as enlarges the set of the characteristics describing ANSPs and making more realistic the analysis, sometimes the inclusion of correlated variables may hide under-performing aspects. As a matter of fact, in the case of DFS, the second analysis does not allow us to understand that it is really under-performing with regard to delays.

Further considerations: when correlation is good, when it is bad and how to manage it when itis bad.

Clearly there are advantages in having larger data set to complete a DEA analysis, but there are minimal requirements as well. First of all the number of DMUs.

Boussofiane et al. in their article (1991) suggested the following rule to lower bound the number of DMUs: they have to be as minimum as the product of the number of inputs and the number of outputs. This came from the issue that there is flexibility in the selection of weights to assign to input and output values in determining the efficiency of each DMU, for a DMU to be efficient, we may assign all of its weight to a specific input or output to appear efficient.

So it can be said that correlation between data are not good when the large number of inputs and outputs threatens the discriminatory power of DEA, which means that it allows too many DMUs to stay on the efficient frontier. In our case 5 flows to describe a sample of 37 ANSPs are considered a good ratio and excluding some flows is not necessary.

However, in the case where we have to manage too many flows, correlated variables should be excluded. One way to identify highly correlated data is to use Principal Component Analysis (PCA).

Adler and Golany (2002) [22] suggested, using PCA, a methodology that produces uncorrelated linear combinations of original inputs and outputs, to improve discrimination in DEA with minimal loss of information. This approach assumes that the variables can be divided into groups, based on their logical composition, and then replaced with principal components representing each group separately. This computation improves the discriminatory power within DEA, which often fails when there are too many inputs and outputs in comparison to the number of DMUs.

This is not clearly our case, but we can take some suggestions from there.

This analysis allows us to say that efficiency differs for different group of input and output even if they include correlated data. So it can be stated that in DEA each variable has its own weight and can influence the computation.

In conclusion we have, also, to deal with the following trade-off:

- inclusion of correlated variables allows us a better description of ASNPs characteristics;
- correlated variables threaten the discriminatory power of DEA.

7.6 Test Four

7.6.1 Data Used.

The fourth test considers the **complexity**.

This analysis thus handles five flows:

1. ATM/CNS provision costs;
2. ATCOs in OPS;

3. total IFR flights controlled by the ANSP;
4. composite flight hours;
5. complexity.

7.6.2 Meaning of the analysis.

This analysis is a tool to understand how much influence an exogenous factor has, e.g. the ″complexity″ on the calculation of the efficiency value. In this analysis we investigate also how we have to handle exogenous factors. Test 4 will not be calculated with a simple DEA analysis, but DEA will work together with a Regression Analysis.

7.6.3 Focusing on Complexity.

The ″en route delays″ are strongly linked to the ″complexity″, inasmuch the greater the traffic the greater will be the difficulty in managing it, consequently, it will be simpler to cause delays. Thus, an ANSP with an high complexity score can be, in some way, "‘excused"’ for inefficiencies.

Let us have an overview on the ″complexity″ data to understand how we can include it in the analysis.

Undesirable Input.

An ANSP is more efficient than another one if, with the same value of ″en-route delays″, it has a higher ″complexity″. Generally speaking it could be noted that between two ANSP, with the same output level, the one with the bigger complexity will result more efficient than the others.

From this statement the ″complexity″ can be described as an ″undesirable input″:

- **input** because it's an ANSP feature, that cannot be modified as I cannot decide to have less or more traffic to manage;

- **undesirable** because the bigger it is the higher the efficiency, contrary to a normal input.

It should be noted, also, that the "complexity" does not behave as a normal input and it is, moreover, considered a **non-discretionary variable**.

Non discretionary variable.

A non discretionary variable is a condition beyond the control of an ANSP, a sort of "exogenous factor", which is fixed and cannot be adjusted.

Complexity's inclusion as a non discretionary input leads to a simple modifications of DEA program in which we reduce input rows and we transform the non discretionary input into a negative output. Afterwards, in the analysis, when we impose an input oriented measurement of efficiency, our *exogenous factor* is not improved, because it is considered an output.

Undesirable and Non Discretionary Input.

Including Complexity data in the analysis is not so easy, because we have to consider also its undesirable nature: among ANSPs with the same output level, the ones with the higher value of complexity would be more efficient than the other ones.

It's reasonable to conclude that the complexity will be included in the analysis as an output, because it's a *non-discretionary input* in an *input oriented measurement of efficiency*, and it will preserve its positive value, because it's an "undesirable input", which means that for higher values of complexity, ANSPs will gains higher efficiency values.

In any case it should be added that the R library Benchmarking does not have any problems in dealing with negative inputs or outputs, as, on the contrary, do most software solutions.

Even if, the consideration appears to work well, transforming a *non-discretionary input* in an output without transforming it into a negative value, it is the same as considering it as an undesirable input, so how can I consider it as an exogenous factor, as it is?

In their article [23], Z. Hua, Y. Bian, L. Liang deals with the problems of having both *undesirable output* and *non-discretionary input*, which have to be considered together.

First they introduce the solutions presented by different authors about the way *undesirable output* should be treated, as Fare et al. (non-linear programming)[18], Seiford and Zhu [16](radial DEA model) and Vencheh et al. (develop a DEA-based model to evaluate efficiency in case of both undesirable input and outputs)[24]. Then they mention the first authors who talk about *non-discretionary input*, Banker and Morey [25], who define them as *exogenously fixed factors* and, finally, Ruggiero. At the end they summarize two different ways in disposing of the *non-discretionary input* in DEA analysis: including them or not including them.

When *non-discretionary inputs* are included in the DEA model, units that operate in similar environment have to be compared with the ones which do not and Ruggiero [23] solves this problem by considering the environment as a discontinuity between the production possibility sets in different environments. But this method cannot be applied in case of *undesirable output*, because the model assumes positive impact of *non-discretionary input* on desirable outputs.

We have to keep in mind that we must consider both impacts that *non-discretionary input* has on desirable and also undesirable outputs. First, the article proposes considering this impact simultaneously using a DEA based non-radial model able to augment each desirable output and each transformed undesirable output simultaneously with different proportions in an output oriented model (keeping Non Discretionary input constant). This is a proper solution which solves perfectly our problem, but it assumes a non-radial mesaure, that R cannot work with.

Complexity can be included in the analysis with the following assumptions/hypothesis:

1. it is an *undesirable input*. A high "‘complexity"’ value leads to greater efficiency;

2. it is an exogenous factor, so a *Non Discretionary input* since it remains constant.
   Thus we have to consider it as an output in a input oriented measure. In this way we are avoiding its increases;

3. we have still to keep in mind its influences on good outputs and bad outputs simultaneously.

So, how should we consider the **complexity** in our analysis?
As the *non-radial measure* is not already implemented in R, one solution is given by making a linear regression between:

- **the final efficiency** that regards:
  - 2 inputs:
    1. the *provision costs;*
    2- the *ATCOs in OPS;*
  - 3 outputs:
    1. the *composite flight hours;*
    2. the *total movement;*
    3. the *en-route delays*
- **the complexity.**

The *regression analysis* shows the link between a variable, called output Y, and one or more input variables X.

7.6.4 The relation between "Complexity" and "Efficiency".

Before continuing with the regression analysis, we need to pay attention to the efficiencies we have obtained in **test 2b**. If we put in the abscissa the *"complexity"* and in the ordinate the *"2b efficiency"* we can see if, for any ANSP, a low efficiency score can be explained by a high score of complexity.

The plot (7.6) can be divided into 4 areas which describe the characteristics of the ANSPs lying in. The 4 groups to consider are:

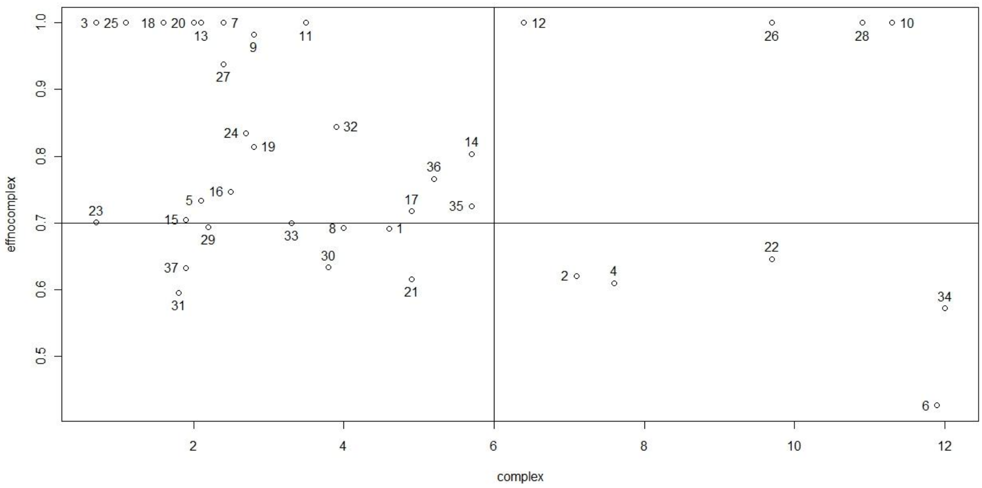

Figure 7.6: Efficiency vs. Complexity.

1. **"Top left-hand area".**
   ANSPs with a low complexity and which have high efficiency. It's clear how their management is simpler thanks to the low complexity level.
   Among them the ANSPs with efficiency equal to 1 are ARMATS, MoldATSA, IAA, EANS, LGS, BULATSA, DHMI.

2. **"Lower left-hand area".**
   ANSPs with a low complexity and low efficiency. They are under-performing even if they might be advantaged by their low complexity.
   They are Oro navigacija, UkSATSE, LPS, NAVIAIR.

3. **"Upper right-hand area".**
   ANSPs with a high efficiency and high complexity. They are really good at managing their obstacles.
   They are: MUAC, NATS, DFS and DSNA.

4. **"Lower right-hand side".**
   ANSPs which have very low efficiency with very high complexity.

They deserve a deeper analysis to see if their efficiencies increase considering the exogenous factor.
They are: Belgocontrol, Skyguide, LVNL, AustroControl, ANS CR.

7.6.5 DEA with Regression Analysis.

This analysis will deal with two variables:

1. **the efficiency,** calculated considering 5 flows and divided as follows:
   - **Inputs:**
     1. *ATM/CNS provision costs;*
     2. *ATCOs in OPS;*
   - **Outputs:**
     1. *total IFR flights controlled by the ANSP;*
     2. *composite flight hours;*
     3. *en-route delays*.
2. **the complexity**.

As stressed above, the following analysis will not be computed as previously. The calculation of the efficiency influenced by the introduction of the complexity as a non-discretionary variable will follow the article *"Resource efficiency in public schools: a study of Connecticut data"*[26].

In this article the community socio-economic status are separated from the normal inputs and are excluded from the DEA model. Then the exogenous variables are used in a subsequent regression analysis with the measure of efficiency obtained previously from DEA as the dependent variable.

The article follows the discussion for the single-output case made by Ray (1988)[26].

He suggested 3 practical steps to allow the calculation of efficiency, even in the case of having *non-discretionary input*:

1. specifying the output vector and the input vector and computing efficiencies with DEA;
2. specifying the external factors affecting output but not under control of the decision-making units. These reflect **advantages** and **disadvantages** in the area where ANSPs are working;
3. estimating a suitable statistical relation between measured efficiency and the external factors.

This strategy fits perfectly our target. First it allows us to treat the exogenous factor, the complexity, as fixed and indivisible non-discretionary input and, secondly, it avoids the free disposability assumption respecting these inputs implicit in the earlier applications.

The **Regression Analysis** shows the relationship between the following two variables: the *efficiency*, as the dependent one, and the *complexity*, the independent one. Usually as the dependent variable is assumed the one which is affected by noise in the measurements, while the independent one has no noise.

First of all the *correlation* between the two has been calculated, which is:

corr = -0.2226259.

The negative sign of the correlation shows that an increase in the complexity is followed by a decrease in the efficiency. The value, indeed, is really low so the following analysis will not describe perfectly the behavior of the variables.

A linear model is found with R with the function lm(y), that gives those two values:

intercept = 0,8469
coefficient = -0,0112.

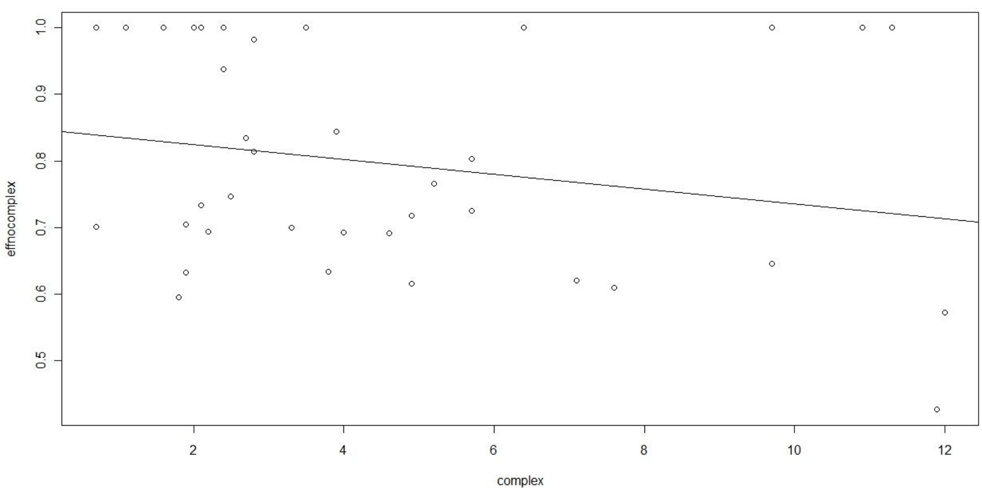

Figure 7.7: Linear Model between Efficinecy and Complexity.

In Figure (7.7) is shown the line approximating my model.

From the *"summary"* given by the software we can look at the principal features. It is important to concentrate on the *Multiple R-squared*, which has a very low value:

Multiple R-squared = 0,04956.

It means that the relation between our two variables is too weak to design a mathematical model on it, consequently our linear model will not give us perfect informations.

As we can see in Figure (7.8) the residuals are really high.

Afterwards, having found the intercept and the coefficient, which are respectively $0,8469$ and $-0,0112$, we are assuming that the complexity is a **disadvantage** variable. This is because the bigger it is, the greater will be the difficulties in managing it, so the efficiency value would gain some "bonus".

So our predicted value h' is described as follow:

h′ = 0,8469 - 0,0112 X complexity.

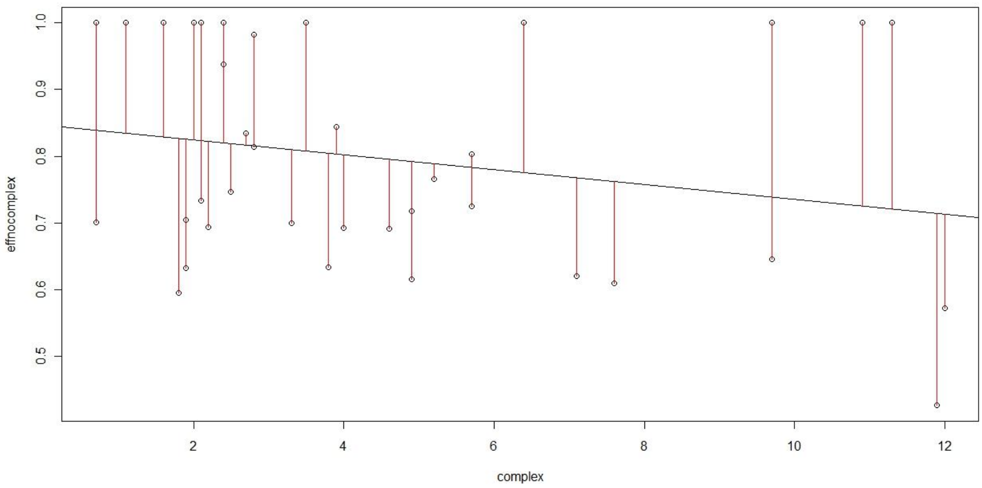

Figure 7.8: Residuals.

Because h' cannot fall below the observed value h, a simple adjustment of the intercept term solves this problem. *Greene* [27] stated that, adding the largest positive residual to the intercept and recomputing the residuals by subtracting this value from each residual obtained by least square, we can avoid this problem, so:

h″ = h′ + max (residuals(mod)).

In our case the maximum value is 0.27962 so the adjusted efficiency becomes:

h″ = h′ + 0.27962.

At that point we are dealing with three different values:

- h, the origianl efficiency computed;

- h', the predicted one;

- h'', the adjusted one.

Hence $(h'' - h)$ is the extent of *managerial inefficiency* not caused by external factors.

Efficiency of one ANSP is now measured from another point of view. First of all, we are considering the *managerial inefficiencies*, which has to be read in this way: the larger the final value, the worse the efficiency of the ANSP.

Secondly this new value is measured as the difference between the adjusted efficiency, h'' and the initial efficiency h (and not between it and 1). In this way the biggest part of what appeared to be inefficient management of resources by the administration, achieves now a new meaning which represents also the disadvantageous exogenous factors.

A h'' exceeds the maximum efficiency value, 1, it is possible to compute the managerial inefficiencies as $(1 - h)$. It must be noted that it is not such an equal approximation, as, for a given unit, more advantaged it is, more it will exceed 1. Thus managerial inefficiencies are underestimated for those ANSPs.

7.6.6 Final Picture.

Table (7.9) shows three columns of efficiency values.

Column 1: refers to the efficiency computed without including the "complexity" in the analysis.

Column 2 and 3: refer to efficiency analysis including the complexity and they are showing the managerial inefficiencies values. While **Column 2** accounts for it as the difference between h and h'', approximated to 1, **Column 3** accounts it as the same difference, but without approximating h'' to 1.

Previously it was stated that an approximation of h'' to 1 could bring benefits to the less disadvantaged ANSPs. As a matter of fact Column 1 and Column 2 show the same ranking: ANSPs with a high score of complexity, such as Skyguide or Belgocontrol, do not gain any benefits accounting for the "complexity".

Column 1		Column 2		Column 3	
Test 2b Efficiency vallues.		Managerial Inefficiency ($h'' \approx 1$)		Managerial Inefficiency	
IAA	1,0000000	IAA	0,000	DFS	0,000
DHMI	1,0000000	DHMI	0,000	NATS	0,004
DFS	1,0000000	DFS	0,000	MUAC	0,018
MoldATSA	1,0000000	MoldATSA	0,000	DSNA	0,055
LGS	1,0000000	LGS	0,000	DHMI	0,087
EANS	1,0000000	EANS	0,000	BULATSA	0,100
DSNA	1,0000000	DSNA	0,000	EANS	0,103
ARMATS	1,0000000	ARMATS	0,000	LGS	0,104
NATS	1,0000000	NATS	0,000	IAA	0,109
MUAC	1,0000000	MUAC	0,000	DCAC Cyprus	0,113
BULATSA	1,0000000	BULATSA	0,000	MoldATSA	0,114
DCAC Cyprus	0,9823039	DCAC Cyprus	0,018	ARMATS	0,119
NATA Albania	0,9382410	NATA Albania	0,062	NATA Albania	0,161
PANSA	0,8440091	PANSA	0,156	PANSA	0,239
M-NAV	0,8343297	M-NAV	0,166	ENAV V	0,260
LFV	0,8139119	LFV	0,186	M-NAV	0,262
ENAV V	0,8029633	ENAV V	0,197	LFV	0,281
SMATSA	0,7661498	SMATSA	0,234	SMATSA	0,302
HCAA	0,7468608	HCAA	0,253	Slovenia Control	0,338
Avinor	0,7333552	Avinor	0,267	HCAA	0,352
Slovenia Control	0,7248163	Slovenia Control	0,275	HungaroControl	0,355
HungaroControl	0,7170211	HungaroControl	0,283	Avinor	0,370
Finavia	0,7043980	Finavia	0,296	LVNL	0,372
MATS	0,7002896	MATS	0,300	Aena	0,384
ROMATSA	0,6998612	ROMATSA	0,300	ROMATSA	0,390
NAV Portugal	0,6934161	NAV Portugal	0,307	Croatia Control	0,390
Croatia Control	0,6918450	Croatia Control	0,308	Finavia	0,401
Aena	0,6913706	Aena	0,309	NAV Portugal	0,408
LVNL	0,6454580	LVNL	0,355	MATS	0,418
NAVIAIR	0,6327976	NAVIAIR	0,367	Skyguide	0,421
UkSATSE	0,6325068	UkSATSE	0,367	ANS CR	0,427
ANS CR	0,6204779	ANS CR	0,380	Austro Control	0,431
LPS	0,6154652	LPS	0,385	NAVIAIR	0,451
Austro Control	0,6099234	Austro Control	0,390	LPS	0,456
Oro navigacija	0,5953306	Oro navigacija	0,405	UkSATSE	0,473
Skyguide	0,5714914	Skyguide	0,429	Oro navigacija	0,511
Belgocontrol	0,4258574	Belgocontrol	0,574	Belgocontrol	0,567

Figure 7.9: Managerial Inefficiency.

Indeed, looking at the ranking, in Column 3, given by the difference between h'' and h we can see the following differences, which tell us how much the "complexity" helps the most disadvantaged ANSPs and if their previous low efficiency values may be motivated by an high level of complexity.

Excellent.

Focusing on the excellent group of Column 1: IAA, DHMI, CFS, MoldATSA, LGS, EANS, DSNA, ARMATS, NATS, MUAC, BULATSA and comparing each own rank with the one obtained in Column 3, it can be noted:

- only DFS and NATS has no managerial inefficiencies, even if both have high complexity scores, respectively 11.3 and 10.9;

- the others follow the two in the same order of their complexity score. In this way DCAC Cyprus (which was no on the efficiency frontier) overtakes BULATSA and comes closer to its peer unit EANS.

Under-Performing.

These are the ANSPs, which have an efficiency score lower than 0.7 in Column 1:

1. LVNL;
2. NAVIAIR;
3. UkSATSE;
4. ANS CR;
5. LPS;
6. Austro Control;
7. Oro navigacija;

8. Skyguide;
9. Belgocontrol.

The followings things may be noted.

- ANSPs deserving special attention are Skyguide and Belgocontrol. As a matter of fact they have the greatest complexity score and the worst efficiency values in the analysis not accounting the complexity, but only with the last analysis we can say if their under-performing managements are dues to the high complexity score or to real inefficiencies. In the case of Skyguide, it gains 7 positions towards a better efficiency value, so we can conclude that part of its bad-working behavior was related to its big complexity.
  Indeed Belgocontrol remains the most under-performing ANSP, even if its efficiency value increases.
- Looking at the others, LVNL gains noticeably more advantage from the last analysis, while UkSATSE is the one which is most disadvantaged.

Among the whole sample of ANSPs a ranking may be made of the most advantaged ones and the most disadvantaged ones by the inclusion of "complexity". If we read the managerial inefficiency as a general inefficiency, we can subtract it from 1 and have a new efficiency value k' to compare with the one in the Column 1. Subtracting k' from the values in Column1 it has been highlighted who takes advantage and who does not: big shortfall between the two means that the inclusion of complexity lowered the efficiency, while small differences between the two efficiency (or even in the case in which k' is higher than the first one) means that the ANSP benefits from it.

Afterwards, looking at the ranking of the shortfalls between the two efficiencies we have noted that:

- the ones gaining more advantages are:
  1. LVNL;

2. MUAC;
3. NATS;
4. DFS;
5. Belgocontrol;
6. Skyguide;

- the most disadvantaged ones are:

1. ARMATS;
2. MATS;
3. MoldATSA;
4. IAA;
5. Oro Navigacija;
6. Finavia;
7. UkSATSE.

As a matter of fact, the latter ranking,in increasing order, reflects perfectly the complexity score ranking, in increasing order, so we can conclude that the regression analysis influences the efficiency value in a proportional way.

7.7 Conclusions.

Six analysis have been made to measure the ANSPs efficiencies.

Each time, in the DEA analysis, different inputs or outputs were included or same elements were treated differently. In the last test a regression analysis it has been used together with DEA.

We have seen how inputs and outputs have to be considered, the first as resources used and the second ones as what's produced thanks to those resources.

After that were taken in account some data which were described as, for example, inputs, but do not behave as them in the DEA analysis. Thus, we have understood what a bad-output and non-discretionary input are. To make those data fit perfectly with a DEA analysis different strategies have been used and their characteristics have been highlighted.

7.7.1 Technical remarks.

The following conclusions have been made:

Bad Outputs. To treat bad outputs three direct approaches are used. One of them replace the undesirable output in the input group, the others two continue to include the Bad Outputs in the output group.
Bad Outputs to remain in the output group need to be modified in their reciprocal number or to be subtracted from a sufficiently big K. Among the three different treatments used, the one accounting the reciprocal number of the bad output as an output is the most selective one, which grants a good work of DEA.

Zeros in data. Data equal to zero need special attention also. Depending on which is the mean of the zero, i.e. it is a missing data or it represents a null quantity, and which is its group, i.e. inputs one or outputs one, different strategy have to be taken.
In our case the zeros mean a null quantity and it is used only as input. As we are using an ”input efficiency measure” to treat zero as itself does not induce any problems.

Non Discretionary Input. The package Benchmarking in R doesn't allow us to include this type of data in the DEA analysis, as a non radial measure is still not yet implemented in this software.
For that a regression analysis has been used. Thus DEA could meet some problems in considering exogenous factors.

7.7.2 Differences between results.

Among the 6 analysis the following performances have been highlighted.

Efficiency Mean.

The lowest mean efficiency score is given by test 5, that doesn't include correlated variable, while the highest mean value is given by test 2a, where undesirable outputs are treated as input.

Optimal ANSPs.

Test 2a (approach BoI) and test 2c (approach KI) allow 15 ANSPs to lay on the efficient frontier and they are the ones which consider optimal the most numerous group of ANSPs. On the contrary the test which is most selective is test 3, which selects only 7 ANSPs as excellent.

Given that good tool for benchmarking has to be as more selective as possible to allow an objective analysis, it can be stated that:

- among the tests that include Undesirable Output should be chosen test 2b, in which Bad Outputs are included in the output group as their reciprocal number;

- test 3, which deals with the strictly necessary flows handling the minimum number ever, is the most selective one.

The ANSPs which lie on the efficient frontier in the whole group of 6 analysis are the following:

1. ARMATS;

2. DHMI;

3. DSNA;

4. EANS;

5. MUAC;

6. NATS.

However, the latter test underlines that there is only one ANSP which has not managerial inefficiency at all, it is DFS.

Under-performing ANSPs.

The ANSPs which always gain an efficiency value inferior to 0.6 are:

1. Oro Navigacija;
2. Skyguide;
3. Belgocontrol.

As a matter of fact Skyguide and Belgocontrol "‘suffer"’ a big complexity score, while Oro Navigacija has even one of the lowest complexity value. This in the last test allows Skyguide to gain 7 places in the efficiency ranking, while the other two remain at the bottom of the ranking.

Table 7.6: Summary.

Test	Mean Efficiency	Optimal ANSPs	The 5 worst ANSPs
1	0.758	1. DFS 2. MoldATSA 3. MUAC 4. EANS 5. DSNA 6. ARMATS 7. NATS 8. DHMI	Skyguide BULATSA Oro Navigacija ROMATSA Belgocontrol
		1. DFS 2. MoldATSA 3. MUAC	

Table 7.6: Summary.

Test	Mean Efficiency	Optimal ANSPs	The 5 worst ANSPs
2a	0.848	4. EANS 5. DSNA 6. ARMATS 7. NATS 8. DHMI 9. ENAV 10. LGS 11. Hungaro Control 12. BULATSA 13. NAV Portugal 14. IAA 15. SMATSA	Skyguide Belgocontrol LPS Austro Control Oro Navigacija
2b	0.795	1. DFS 2. MoldATSA 3. MUAC 4. EANS 5. DSNA 6. ARMATS 7. NATS 8. DHMI 9. IAA 10. LGS 11.BULATSA	Oro Navigacija Belgocontrol Skyguide Belgocontrol LPS Austro Control
		1. DFS 2. MoldATSA 3. MUAC 4. EANS 5. DSNA 6. ARMATS 7. NATS	Skyguide Belgocontrol

Table 7.6: Summary.

Test	Mean Efficiency	Optimal ANSPs	The 5 worst ANSPs
2c	0.843	8. DHMI 9. ENAV 10. LGS 11. Hungaro Control 12. BULATSA 13. NAV Portugal 14. IAA 15. SMATSA	LPS Austro Control Oro Navigacija
3	0.711	1. IAA 2. MUAC 3. EANS 4. DSNA 5. ARMATS 6.NATS 7. DHMI	Slovenia Control LPS Oro Navigacija LVNL Belgocontrol
4	0.280	1. DFS	Belgocontrol NAVIAIR LPS Oro Navigacija UkSATSE

7.7.3 Focusing on ANSPs one by one.

In the following sections, for each ANSP the efficiency scores gained in the six analysis are shown in the table. The values in the first three columns represent the level of efficiency: the higher the value the more optimal the ANSP. Indeed, the fourth column shows the managerial inefficiency value, which has to be read as follows: the smaller it is the higher the efficiency. The latter column contains the complexity score.

Aena, Spain.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,691	0,691	0,566	0,384	4,6

Table 7.7: Aena's Efficiencies.

Besides the fact it is part of the 5 largest ANSPs it has always low efficiency score, while the others are even optimal. In the total ranking Aena occupies a low average position.

The inclusion of "en-route delays" lowered its rank, while considering its "complexity" dues to an increase of its rank.

Test 3 highlights his big amount of "provision cost".

ANS CR, Czech Republic.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,620	0,620	0,597	0,427	7,1

Table 7.8: ANS CR's Efficiencies.

This ANSP covers a low position in the total rank, moreover despite its complexity is within the 10 highest values, ANS CR's efficiency score does not benefit from it.

ARMATS, Armenia.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	1,000	0,119	0,7

Table 7.9: ARMATS's Efficiencies.

It is one of the six ANSPs which lie on the efficient frontier in all the firsts 3 tests.

It benefits from its "en-route delays" amount of 0 minute, otherwise its complexity score, the lowest one, does not help it in gaining greater efficiency value.

Austro Control, Austria.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,610	0,610	0,580	0,431	7,6

Table 7.10: AustroControl's Efficiencies.

This ANSP has low efficiency values in the whole analysis which put it in the lowest positions of the total ranking. Austro Control has a great amount of ”en-route delays”, which is not motivated by its ”complexity”.

Avinor, Norway.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,733	0,733	0,733	0,370	2,1

Table 7.11: Avinor's Efficiencies.

We are dealing, now, with one ANSP which has a low complexity and which, compared to the others ANSPs, which has similar complexity, has the highest values of provision cost. As a matter of fact it produces a large number of composite flight hours.

Avinor maintains constant its efficiency and in the general ranking it occupies an average position.

Belgocontrol, Belgium.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,259	0,426	0,318	0,567	11,9

Table 7.12: Belgocontrol's Efficiencies.

Belgocontrol is one of the most interesting ANSP: the first test highlights it as the worst ASNP, with a very low score of efficiency (the second latter value is 0.509), then it has a good improvements accounting the ”en-route delays” in the analysis, but it still remains the worst one. Moreover, the high score of ″complexity″ does not improve its efficiency, even if it has the second highest value.

In the total ranking Belgocontrol always lies at the bottom.

BULATSA, Bulgaria.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,560	1,000	0,745	0,100	2,4

Table 7.13: BULATSA's Efficiencies.

The great increase in the efficiency follows the introduction in the outputs' group of ″en-route delays″. If we come back to the data table we note that BULATSA is one of the ANSPs which has 0 minute of ″en-route delays″. Obviously this feature counts a lot in the analysis. The last efficiency has a little decrease. BULATSA is one of the ANSPs which has the most significance changes in the general ranking: from its bottom position in the first step, BULATSA grows in 2b and is part of the ″optimal ANSP″ group. Test 3 lowers a lot its ranking, but the ″complexity″ put it among the six most efficient ANSPs.

Croatia Control, Croatia.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,692	0,692	0,692	0,390	4,0

Table 7.14: Croatia Control's Efficiencies.

Croatia Control is good regarding the provision costs, while it has quite a large value of en-route delays. These are its strength and its weakness but, generally, its data lie on an average situation, without any strong peak which can affect the efficiency. Crotia Control's rank is in the low average part of the total efficiency values for the whole sample of the 37 ANSPs.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,982	0,982	0,746	0,113	2,8

Table 7.15: DCAC's Efficiencies.

DCAC, Cyprus.

It is characterized by restricted inputs, low provision cost and low ATCOs in OPS, and also restricted outputs, such as "composite flights hours" and "total IFR flights movement". For that DCAC gains great efficiency values which allow it to stay in the upper part of the toal rankings.

DFS, Germany.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	0,825	0,000	11,3

Table 7.16: DFS's Efficiencies.

DFS has an interesting development in the tests. In the firsts test it lies on the efficient frontier and it's part of the group of the "universally efficient" ANSPs (the ones which gain always an efficient value equal to 1). Among this group DFS is the only one which, in test 3, lowers its efficiency value. At the same time in test 4 it is the only one with a managerial inefficiency equal to 0. Its data are always among the three biggest values of each column of data considered, so even if it has the largest input (negative fact), it produces the largest output (positive fact). We can see one of the strengths of DEA: the ability to compare such different situations, in an equal way.

DHMI, Turkey.

DHMI is "universally efficient" and its part of the 6 changeless ANSPs. Its managerial inefficiency, underlined in test 4, stresses that it is the fifth best performing ANSP.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	0,825	0,000	11,3

Table 7.17: DHMI's Efficiencies.

DSNA, France.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	1,000	0,055	6,4

Table 7.18: DSNA's Efficiencies.

DSNA is ”universally efficient”. Interesting to note is that DSNA is the ANSP, with Aena, which has the highest values of input. Similarly it is the one which produces the largest amount of output, with DFS. However, while Aena and DFS have some inefficiencies, DSNA always lies on the efficient frontier. Its managerial inefficiency is in the fourth best performing position.

EANS, Estonia.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	1,000	0,103	2,1

Table 7.19: EANS's Efficiencies.

EANS is ”universally efficient”, but its low complexity leads to a higher value of managerial inefficiency, in comparison to the others ”universally efficient” ANSPs.

ENAV, Italy.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,798	0,803	0,718	0,260	5,7

Table 7.20: ENAV's Efficiencies.

ENAV in the general rankings of efficiency values gains upper positions. As a matter of fact looking at its data it is possible to note that it has high amount of input related to high amount of output, with a quite low level of ”en-route delays”. Its development through the 6 analysis is constant and underlines a satisfactory performance.

Finavia, Finland.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,704	0,704	0,704	0,401	1,9

Table 7.21: Finavia’s Efficiencies.

Looking at data are not underlined any strong inefficiencies or particular strengths. Finavia is able to handle its traffic producing a small amount of ”en-route delays”, but its managerial inefficiency is quite high, compared to the whole sample.

HCAA, Greece.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,747	0,747	0,747	0,352	2,5

Table 7.22: HCAA’s Efficiencies.

HCAA efficiency value remains constant among tests. In the general ranking it occupies an average position, although HCAA produces quite high ”en-route delays” related to its capacity.

Hungaro Control, Hungary.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,717	0,717	0,717	0,355	4,9

Table 7.23: Hungaro Control’s Efficiencies.

Hungaro Control gains during the whole sample of the analysis an average efficiency score.

IAA, Ireland.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,728	1,000	1,000	0,109	1,6

Table 7.24: IAA's Efficiencies.

IAA is one of the few ANSPs which benefits from the ”en-route delays” inclusion and from the analysis that does not consider correlated variables. As it's possible to note its efficiency value increases from test 1 to to test 2b and IAA becomes part of the efficient ANSPs. It has one of the biggest positive gap between its position in test 1 and its position in the other tests and its managing inefficient is remarkable low. However IAA benefits from its ”en-route delays” equal to 0 and from its low ”complexiy”.

LFV, Sweden.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,812	0,814	0,814	0,281	2,8

Table 7.25: LFV's Efficiencies.

LFV uses quite big quantity of input, but produces high level of outputs as same as, all related with a small amount of ”en-route delays”. In the general ranking LFV gains an upper average position.

LGS, Latvia.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,736	1,000	0,799	0,104	2,0

Table 7.26: LGS's Efficiencies.

LGS can be considered one of the smallest ANSPs among the 37 considered and for that it benefits of 0 minutes of ”en-route delays” and a low complexity. However its managerial inefficiency is really low, which means that, despite the benefits described above, LGS has a good way of working.

LPS, Slovak Republic.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,615	0,615	0,362	0,456	4,9

Table 7.27: LPS’s Efficiencies.

LPS has an under-performing management. Despite test 1, it is always part of the 5 worst ANSPs. Moreover its efficiency value has a decreasing trend.

LVNL, Netherlands.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,645	0,645	0,353	0,372	9,7

Table 7.28: LVNL’s Efficiencies.

LVNL’s low efficiency score underlines its big amount of ”provisional costs” in comparison to the ”composite flights hour” produced. Moreover LVNL has a quite high value of ”en-route delays”. Despite a decreasing trend of its efficiency value, LVNL benefits from the inclusion of the ”complexity” in test 4. In the general ranking LVNL, from test 3 to test 4, makes a big positive jump towards total efficiency.

LVNL’s most serious problem is the high amount of ”provisional costs”.

MATS, Malta.

MATS has average performance, which does not benefit from the test with no correlated flows and moreover does not benefit from accounting the

Test 1	Test 2b	Test 3	Test 4	Complexity
0,700	0,700	0,661	0,418	0,7

Table 7.29: MATS's Efficiencies.

"complexity". As a matter of fact its ranking is lowered a lot with test4.

M-NAV, Macedonia.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,700	0,700	0,661	0,418	0,7

Table 7.30: M-NAV's Efficiencies.

The efficiency value of M-NAV falls down if DEA model is computed with the input and output groups of test 3. M-NAV's weakness can be seen in its really low quantity of output produced, despite its low score of "complexity".

MoldATSA, Moldova.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	0,948	0,114	1,1

Table 7.31: MoldATSA's Efficiencies.

MoldATSA is the ANSP which produces less output at all. Despite it it gains optimal efficiency values among the different tests.

It has a little decrease of efficiency in test 3, which do not consider "ATCOs in OPS" and "total movements", and also in test 4. Its managerial inefficiency it's quite big, if we compare it with the "managerial inefficiencies" of the ANSPs, that have an optimal efficiency value trend.

MUAC.

As it was introduce before, MUAC is a particular ANSP. MUAC handles the air traffic over Benelux territory, but it leans part on the German ANSP

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	1,000	0,018	9,7

Table 7.32: MUAC's Efficiencies.

and part on the Belgium one. It is ”universally” efficient and in the rank of the managerial inefficiencies it has the third lowest value.

NATA Albania, Albania.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,938	0,938	0,498	0,161	2,4

Table 7.33: NATA Albania's Efficiencies.

The difference in its efficiency value between the first tests and the third one is clearly relevant. This difference highlights some strong weakness, which could be the low quantity of ”composite flights hour” produced. However in test 4 NATA gains a positive value of ”managerial inefficiencies”.

NATS, United Kingdom.

Test 1	Test 2b	Test 3	Test 4	Complexity
1,000	1,000	1,000	0,004	10,9

Table 7.34: NATS's Efficiencies.

NATS has a really efficient management. This is underlined also by its low amount of ”en-route delays”, compared with the ”en-route delays” of its similar ANSPs, like DFS and Aena. This positive characteristic can be seen also looking at the efficiency value gained in test 3, that, among the four tests, is the one most selective and can be seen also in its managerial inefficiencies value, which is the best second one, after DFS.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,693	0,693	0,599	0,408	2,2

Table 7.35: NAV Portugal's Efficiencies.

NAV Portugal, Portugal.

NAV Portugal has an under-performing trend looking at its efficiency values. In the general ranking even if it's not at the bottom of the list, it has a low position stressed even more if the analysis considers its "complexity" value.

NAVIAIR, Denmark.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,633	0,633	0,616	0,451	3,8

Table 7.36: NAVIAIR's Efficiencies.

NAVIAIR in the general ranking occupies really different positions among the whole sample of tests. Test 2b highlights no strong weakness in managing delays, on the contrary its complexity, in relation with its data, collocates NAVIAIR at the bottom of the general ranking, among the ANSPs with the highest score of managerial inefficiencies.

Oro navigacija, Lithuania.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,559	0,595	0,487	0,511	1,8

Table 7.37: Oro navigacija's Efficiencies.

Oro Navigacija is part of the most under-performing ANSPs. Its efficiency values clearly highlight this trend and the "managerial inefficiencies" defined Oro Navigacija as the second worst ANSP ever.

PANSA, Poland.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,844	0,844	0,844	0,239	3,9

Table 7.38: PANSA's Efficiencies.

PANSA is not part of the optimal ANSPs but its efficiency values show good performances and good possibilities to reach the efficient frontier with not lot of difficulty.

PANSA is characterized by a low amount of provision costs.

ROMATSA, Romania.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,510	0,700	0,700	0,390	3,3

Table 7.39: ROMATSA's Efficiencies.

ROMATSA has an increasing efficiency values among the different tests. Looking at the general ranking, in the first test it is the second worst ANSP among the whole 37, otherwise accounting the ″en-route delays″ ROMATSA gains in efficiency. Moreover the efficiency does not decrease in the third test and ROMATSA, at the end, has an average managerial inefficiencies.

Skyguide, Switzerland.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,571	0,571	0,514	0,421	12,0

Table 7.40: Skyguide's Efficiencies.

Skyguide is the ANSP with the highest ″complexity″, but at the same time it is among the worst performing ANSPs. However the inclusion of ″complexity″ allows Skyguide to gain a better efficiency value, compared to the others low ANSP.

Slovenia Control, Slovenia.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,725	0,725	0,377	0,338	5,7

Table 7.41: Slovenia Control's Efficiencies.

The case of Slovenia Control is particular. In the first two tests it has a quite high efficiency value, that suddenly decreases from 0.7248163 to 0.3766682. This is due to an insufficient quantity of output, considering the input used.

Slovenia's managerial inefficiencies its acceptable, thanks to its pretty high "complexity".

SMATSA, Serbia and Montenegro.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,766	0,766	0,766	0,302	5,2

Table 7.42: SMATSA's Efficiencies.

SMATSA maintains a high average efficiency value among the whole 6 test.

UkSATSE, Ukraine.

Test 1	Test 2b	Test 3	Test 4	Complexity
0,633	0,633	0,633	0,473	1,9

Table 7.43: UkSATSE's Efficiencies.

Despite the fact that UkSATSE appears with a constant efficiency value in the first three tests, in the latter one UkSATSE receives one of the worst value of managerial inefficiencies.

Chapter 8

Appendix.

N°	Country	ANSP
1	Spain	Aena
2	Czech Republic	ANS CR
3	Armenia	ARMATS
4	Austria	Austro Control
5	Norway	Avinor
6	Belgium	Belgocontrol
7	Bulgaria	BULATSA
8	Croatia	Croatia Control
9	Cyprus	DCAC Cyprus
10	Germany	DFS
11	Turkey	DHMI
12	France	DSNA
13	Estonia	EANS
14	Italy	ENAV
15	Finland	Finavia
16	Greece	HCAA
17	Hungary	HungaroControl
18	Ireland	IAA
19	Sweden	LFV
20	Latvia	LGS
21	Slovak Republic	LPS
22	Netherlands	LVNL
23	Malta	MATS
24	Macedonia	M-NAV
25	Moldova	MoldATSA
26		MUAC
27	Albania	NATA Albania
28	United Kingdom	NATS
29	Portugal	NAV Portugal
30	Denmark	NAVIAIR
31	Lithuania	Oro navigacija
32	Poland	PANSA
33	Romania	ROMATSA
34	Switzerland	Skyguide
35	Slovenia	Slovenia Control
36	Serbia and Montenagro	SMATSA
37	Ukraine	UkSATSE

Table 8.1: The sample of the 37 ANSPs.

N°	ANSP	(a)	(b)	(c)	(d)	(e)	(f)
1	Aena	1 309	1 187 505	2 004	1 681 639	1 751 600	4,6
2	ANS CR	182	107 636	187	629 249	266 155	7,1
3	ARMATS	0	6 284	95	48 120	16 326	0,7
4	Austro C.	858	165 934	266	888 732	386 571	7,6
5	Avinor	71	158 022	356	527 555	461 124	2,1
6	Belgocontrol	129	150 222	216	542 404	203 500	11,9
7	BULATSA	0	76 951	216	485 313	185 907	2,4
8	Croatia C.	280	64 323	220	420 613	191 291	4
9	DCAC	621	40 717	68	267 591	137 863	2,8
10	DFS	1 973	887 594	1 714	2 727 654	1 860 706	11,3
11	DHMI	49	242 508	771	828 059	896 279	3,5
12	DSNA	496	1 157 658	2 677	2 700 262	2 608 943	6,4
13	EANS	0	9 826	37	150 624	60 218	2,1
14	ENAV V	17	648 610	1 233	1 532 885	1 332 441	5,7
15	Finavia	6	57 118	194	230 097	175 159	1,9
16	HCAA	714	178 065	530	637 923	525 775	2,5
17	Hungaro C.	15	74 035	172	607 452	223 735	4,9
18	IAA	0	106 922	231	525 810	317 166	1,6
19	LFV	20	166 213	500	650 664	533 250	2,8
20	LGS	0	20 134	73	204 012	76 768	2
21	LPS	19	46 367	101	336 097	86 442	4,9
22	LVNL	21	178 864	177	529 600	261 508	9,7
23	MATS	1	13 499	56	85 294	49 004	0,7
24	M-NAV	0	10 722	67	125 148	24 362	2,7
25	MoldATSA	0	6 630	56	43 778	14 680	1,1
26	MUAC	74	134 603	218	1 484 804	531 873	9,7
27	NATA	19	16 462	41	161 444	40 038	2,4
28	NATS	387	686 714	1 413	2 230 255	1 780 323	10,9
29	NAV	8	134 269	201	402 052	326 994	2,2
30	NAVIAIR	13	112 009	194	587 298	283 701	3,8
31	Oro Nav.	0	18 704	80	157 404	51 375	1,8
32	PANSA	900	117 984	384	552 173	399 485	3,9
33	ROMATSA	0	147 767	513	433 848	307 889	3,3
34	Skyguide	591	217 815	324	1 154 649	446 306	12
35	Slovenia C.	5	24 224	90	233 298	51 524	5,7
36	SMATSA	2	69 502	225	505 889	224 356	5,2
37	UkSATSE	4	137 114	936	377 616	350 897	1,9

Table 8.2: Key Data: (a) En route ATFM Delays ('000 minutes); (b) ATM/CNS provision costs ('000 euro); (c) ATCOs in OPS; (d)Total IFR flights controlled by the ANSP; (e) Composite flight-hours; (f) Complexity score.

		Test 1	Test 2 a	Test 2 b	Test 2 c	Test 3	Test 4
	Inputs:	(a), (b), (c)	(b), (c)	(b), (c)	(b), (c)	(b)	(b), (c), (f)
	Outputs:	(d), (e),	(d), (e),	(d), (e), 1/(a)	(d), (e), K-(a)	(e), 1/(a)	(e), 1/(a)
	ANSP	**Eff.**	**Eff.**	**Eff.**	**Eff.**	**Eff.**	**M. Ineff.**
1	Aena	0,6914	0,6914	0,6914	0,6914	0,5661	0,3836
2	ANS CR	0,6205	0,6205	0,6205	0,6205	0,5974	0,4265
3	ARMATS	1,0000	1,0000	1,0000	1,0000	1,0000	0,1187
4	Austro C.	0,6099	0,6099	0,6099	0,6099	0,5795	0,4315
5	Avinor	0,7334	0,7424	0,7334	0,7334	0,7334	0,3696
6	Belgoc.	0,2586	0,4259	0,4259	0,4259	0,3177	0,5674
7	BULATSA	0,5598	1,0000	1,0000	1,0000	0,7449	0,0996
8	Croatia C.	0,6918	0,6918	0,6918	0,6918	0,6918	0,3899
9	DCAC	0,9823	0,9823	0,9823	0,9823	0,7458	0,1129
10	DFS	1,0000	1,0000	1,0000	1,0000	0,8252	0,0000
11	DHMI	1,0000	1,0000	1,0000	1,0000	1,0000	0,0873
12	DSNA	1,0000	1,0000	1,0000	1,0000	1,0000	0,0548
13	EANS	1,0000	1,0000	1,0000	1,0000	1,0000	0,1030
14	ENAV	0,7983	1,0000	0,8030	1,0000	0,7175	0,2597
15	Finavia	0,7044	0,7912	0,7044	0,7540	0,7044	0,4008
16	HCAA	0,7469	0,7469	0,7469	0,7469	0,7469	0,3517
17	HungaroC.	0,7170	1,0000	0,7170	1,0000	0,7170	0,3546
18	IAA	0,7277	1,0000	1,0000	1,0000	1,0000	0,1086
19	LFV	0,8123	0,9480	0,8139	0,9353	0,8139	0,2812
20	LGS	0,7360	1,0000	1,0000	1,0000	0,7986	0,1041
21	LPS	0,6155	0,6155	0,6155	0,6155	0,3615	0,4562
22	LVNL	0,6455	0,8089	0,6455	0,7543	0,3527	0,3724
23	MATS	0,7003	0,7003	0,7003	0,7003	0,6609	0,4184
24	M-NAV	0,8343	0,8343	0,8343	0,8343	0,6466	0,2620
25	MoldATSA	1,0000	1,0000	1,0000	1,0000	0,9478	0,1142
26	MUAC	1,0000	1,0000	1,0000	1,0000	1,0000	0,0179
27	NATA	0,9382	0,9382	0,9382	0,9382	0,4980	0,1614
28	NATS	1,0000	1,0000	1,0000	1,0000	1,0000	0,0044
29	NAV	0,6934	1,0000	0,6934	1,0000	0,5988	0,4085
30	NAVIAIR	0,6328	0,9273	0,6328	0,9005	0,6156	0,4512
31	Oro nav.	0,5592	0,5953	0,5953	0,5953	0,4872	0,5110
32	PANSA	0,8440	0,8440	0,8440	0,8440	0,8440	0,2388
33	ROMATSA	0,5099	0,6999	0,6999	0,6999	0,6999	0,3897
34	Skyguide	0,5715	0,5715	0,5715	0,5715	0,5140	0,4206
35	Slovenia C.	0,7248	0,7701	0,7248	0,7248	0,3767	0,3379
36	SMATSA	0,7661	1,0000	0,7661	1,0000	0,7661	0,3021
37	UkSATSE	0,6325	0,8316	0,6325	0,8232	0,6325	0,4727

Table 8.3: Efficiency values.(a) En route ATFM Delays; (b) ATM/CNS provision costs; (c) ATCOs in OPS; (d)Total IFR flights controlled by the ANSP; (e) Composite flight-hours; (f) Complexity score.

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