Multidimensional Benchmarking of Air Navigation Service Providers and Application in Functional Airspace Block and Sector Group Context

- Full Paper -

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Abstract
This paper introduces an innovative methodological approach for European ANSP-Assessment. Based on current official reports mandatory improvements regarding the benchmarking methodology could be identified. Furthermore, the amount of information as well as the identification of economic influence factors represents the primary goals of the study. An evaluation of potential methodologies identified the application of the multidimensional Data Envelopment Analysis combined with a Regression Analysis as an appropriate procedure in ANSP assessment activities. In addition, the paper introduces an innovative modular benchmarking scheme for an in-depth investigation of ANSP-Efficiency, extending the described methodology by including an application on different operational levels and the utilization of manifold data sources. This proven method enables the application on a macroscopic level represented by Functional Airspace Context as well as on a microscopic level, represented by the identification of best practices on sector group basis.

Nomenclature

\[
\begin{align*}
I &= \text{Number of firms / Decision Making Units} \\
Q &= \text{Matrix of output data for all firms} \\
q_i &= \text{Data vector of firm } i \text{ (output)} \\
X &= \text{Matrix of input data for all firms} \\
x_i &= \text{Data vector of firm } i \text{ (input)} \\
\Theta_i &= \text{Input efficiency factor of firm } i \text{ (Radial distance between DMU } i \text{ and the frontier production function)} \\
\lambda &= \text{Dual weights for all DMUs and Parameters (vector)}
\end{align*}
\]

¹ PhD student, Junior Researcher – I wish to apply for the Best Paper by a Junior Researcher Prize
I. Introduction

The slogan “Big is beautiful” is promoted by many representatives of the aviation institutions. This assumption led to efforts to consolidate airspaces to Functional Air Space Blocks (FABs), e.g. in order to reduce coordination workload. Whether these FABs can improve ANS efficiency through merging air-spaces is first of all a question of regulations and incentives and secondly a matter of economic preconditions.

Introducing a two stage methodology consisting of Data Envelopment Analysis and Regression Analysis led to significant benefits in implementation and amount of information in ANSP benchmarking efforts. Former results show a significant negative impact of airspace size and the positive influence of sectoring on efficiency values [1], [2]. These results represent a clear statement against the economic argument for the consolidation of air spaces, such as planned for the European ANSP-Sector in the Functional-Airspace-Block (FAB) framework.

However, current performance studies use high operational level data (ANSP), which can be seen as scratching the surface. An efficient running system of ANSPs requires an optimization which includes the consideration of all stakeholders. Both the operational level of sectors or sector groups as well as the application in FAB context is mandatory for gaining knowledge about the system's behaviour. The paper will show the applicability of the methodology in ANSP sector and coverage of all compulsory elements.

In cooperation with the ANSPs within FABEC, the current study uses a three-step-approach in a modular analysis scheme in order to run an in-depth-analysis. The use of new data sources is considered as well as the methodological foundations of a more detailed analysis. Finally, it is also performed at different operational levels.

II. Official benchmarking efforts in ANSP context

During the last two decades, the number of flight movements increased as well as the impact of Low Cost Carriers. In consequence, air navigation service providers, as an important part of the entire system, were faced with both: increasing air traffic and increasing cost pressure by the airline industry. This situation led to enhanced and continuing efforts in order to evaluate and compare the performance of the monopolistic acting ANSPs [3].

The primary aim of performance assessments comparisons is to determine, which ANSP achieves the highest rank of productivity or efficiency. The analysis helps to identify best practices. Furthermore, it will be possible to derive measures for productivity and efficiency improvements, e.g. by the introduction of new technology, redesign of air spaces or improvement of working methods.

Current reports like the ATM Cost Effectiveness Report (ACE) [4] or Performance Review Report (PRR) [5] published by Eurocontrol provide a first approach to ANSP benchmarking. A two-dimensional scheme (one input, one output) is used to rank providers by quantitative or cost-related measures (figure 1).
However, the current reports open a wide research gap in cases of benchmarking methodology and derived potential improvements. Since aviation companies use multiple inputs to produce multiple outputs, two-dimensional analyses seem to be not appropriate in the context of ANSP benchmarking. In this kind of analysis, important cross-effects between inputs and/or outputs are not taken into account.

Additionally the official reports neither differ inefficiency in technical, scalar and allocative components, nor do they cluster or classify ANSPs, e.g. by demand or production function. Even looking one step further, there is no quantification about endogenous and exogenous effects which have a positive or negative influence on efficiency values.

Figure 1: ACE Benchmarking Scheme

In order to make an in depth investigation, it is mandatory to introduce a methodology with the ability to consider multiple inputs and outputs as well as including an extended amount of information. Therefore, a reliable two-stage model is applied in order to investigate efficiency and its drivers.

III. Methodological Background

Since a variety of methodologies revealed weaknesses in implementation and information content, the non-parametric approach of the Data Envelopment Analysis (DEA) is preferred for efficiency investigations. This methodology is scientifically proven and has been used in numerous studies in various sectors of the economy, e.g. [6] and [7].

A scientific approach and detailed descriptions is provided by [8] and [9]. In a second step, the influence of exogenous and endogenous factors on these values is evaluated running a regression analysis.
The analysis has to be based on valid and complete data and the collection process must be carried out in the same manner. By virtue of a set of inputs and outputs, DEA generates a frontier production function using mathematical optimization models and linear programming (figure 2).

Figure 2: Example of DEA optimization model (Dual Form)

\[
\begin{align*}
\min_{\theta, \lambda} & \quad \theta \\
\text{s.t.} & \quad -q_i + Q\lambda \geq 0 \quad \{2\} \\
& \quad \theta_i x_i - X\lambda \geq 0 \quad \{3\} \\
& \quad I1^T \cdot \lambda = 1 \quad \{4\} \\
& \quad \lambda \geq 0 \quad \{5\}
\end{align*}
\]

{1} the minimal input efficiency factor $\theta$ is determined under the constraints,

{2} that the sum of the $\lambda$-weighted input values of all DMUs is not less than the individual output values of the considered DMU and

{3} that the sum of the $\lambda$-weighted input values of all the DMUs does not exceed $\theta_i$-times the individual input values of the considered DMU

{4} the sum of the weighting factors of all evaluation objects must be equal to one

$\rightarrow$ convexity of the production function

{5} the weights must not be negative

The third constraint introduces the consideration of variable returns to scale (VRS-DEA). Each model without this constraint calculates efficiency values in the assumption of constant returns to scale.

The generated production function represents the efficient frontier of technology. This scheme is shown in simplified form in figure 3. The red dots represent efficient units, assessed with an efficiency degree of 1 (100%). The white dots are identified as inefficient.

For inefficient units, DEA calculates the degree of efficiency over distance functions. The methodological inherent clustering prevents from comparing dissimilar units. The corresponding benchmark units may be assigned for any inefficient unit (figure 4).
The model integrated convexity term allows the identification of scalar effects. That means DEA methodology also provides information about types of inefficiencies such as technical, scalar and allocative components. Furthermore, economies of scale can be identified as well as several economic growth rates in multi-period considerations.

Figure 4 illustrates a situation with one output $y$ and two inputs $x_1$ and $x_2$. The red line marks the efficient isoquant of outputs, which contains the efficient units A and B. Additionally, the inefficient unit C is shown. To achieve efficiency, C would have to realize $C^*$ on the isoquant curve. The distance function is represented by the ratio $0C^*/0C$.

In the case of the graph, A and B represent the peer group for DMU C. That means B and A have a comparable production technology relative to C, but work efficient which allows identifying potential improvements for unit C. The blue arrows demonstrate the shared weights of the optimization model. Due to the fact of two inputs in the graph, the sum of the two input weights will be exact 1 (e.g. 0.45 and 0.55).
In order to gain adequate results, it is necessary to choose useful DEA-criteria. This includes the following points:

- **Type of DEA**
  - If there is data for more than one time period available, a so called “Malmquist-DEA” is recommended to gain information about technical and scale efficiency as well as growth rates.
  - For the analysis of a single year and scale effects, a Multistage-DEA is used.

- **Orientation of DEA**
  - Due to the fact, that the output of an ANSP can’t be influenced, the DEA is input orientated.

- **Returns to scale**
  - Variable returns to scale are assumed in order to gain information about the scale effects.

- **Inputs and Outputs**
  - The input and output data have to be chosen on criteria regarding the current objective and purpose of the analysis.
  - For multidimensional analyses, it is recommended to choose segments with low correlation.

On ANSP level, the ACE report provides a large amount of data. The software DEAP 2.1 was used for the DEA calculation. It is a small and easy to handle application to calculate all the efficiency measurements described.

The degrees of efficiency represent the dependent variables for the second stage regression analysis, which allows for an investigation of the influence of operational, geographical, economical, demographical and a wide range of further factors. This also allows identifying efficiency enhancing measures.

The values calculated in the first step DEA represent the dependent variable $y$. The independent variables $x_1$ to $x_n$ are the influencing factors. The variables $a_1$ to $a_m$, which indicate the influence of each independent variable on the efficiency values, will be calculated. In the regression it is possible to assume linear connections as well as quadratic or logarithmic correlation.

$$ y = a_1 x_1 + a_2 x_2 + \ldots + a_n x_n \{6\} $$

Based on the initial solution, it is tested successively by adding, removing or replacing the variables, which model represents the empirical data best. Using statistical tests allows evaluating the quality of the current model. Software often used four criterions: Log-Likelihood, Akaike, Schwarz and Hannan-Quinn. The optimum result is a regression function which achieve a high model quality and where as many variables as possible show statistical significance [10].
Based on the first step that aims to calculate degrees of efficiency, it is the second step to determine the causes. By applying a regression analysis, basically the information listed below may be largely determined:

- Factors (Which factors have an influence on efficiency),
- Intensity (Level of Impact by the factor),
- Direction (Positive or negative correlation) and
- Significance (Statistical significance of the factor).

The efficiency influencing factors may be based on one of the following areas.

- General operational characteristics
- Airspace & airport characteristics
- Traffic characteristics
- Infrastructure & technology
- Staffing, Training & Proficiency
- Safety
- Cost & Finance
- Organisation & Governance
- Project Management
- Social, political and regulatory framework

DEA and regression analysis will be implemented in the innovative benchmarking scheme, which is presented in chapter V.

**IV. Application on macroscopic and microscopic level**

In Europe, the implementation of functional airspace blocks represents a milestone in the Single European Sky concept. From an economic point of view, the consolidation of airspaces represents an incensement of the operational size. The size of a company has a decisive influence on the efficiency achieved. The information about economies of scale gathered by the DEA allows a first assessment of airspace consolidations.

In order to test the applicability, the investigation was based on 29 European ANS providers, observed over a time period of seven years (2003 – 2009). The inputs were represented by the staff as a proxy of human resources as well as the number of ACCs and the number of towers was used as a proxy for fixed capital. Total controlled Flight Hours and the ATFM delay represented the output. The data was derived from Eurocontrol Performance Review Unit (PRU). The DEA run under the assumption of variable returns to scale (VRS). Since the output of the providers is determined by the airlines, the efficiency analysis was performed input oriented [11].

Since VRS-DEA is able to divide inefficiency into a technical and a scalar component, the scale efficiency and returns to scale represent an approach to evaluate airspace consolidation. Figure 5 shows the scale efficient ANSPs coloured in green. Scale inefficient units coloured stepwise from light green (low inefficiency) to red (high inefficiency). Scale inefficiency is caused by a suboptimal operational size. In other words the operational size is too big or too small. This information is provided by the economies of scale.
Figure 5: Scale Efficiency in the year 2009

<table>
<thead>
<tr>
<th>Scale efficiency</th>
<th>Econ. of Scale</th>
<th>Scale efficiency</th>
<th>Econ. of Scale</th>
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<tbody>
<tr>
<td>Albania</td>
<td>0.407</td>
<td>irs</td>
<td>Macedonia</td>
</tr>
<tr>
<td>Austria</td>
<td>1.000</td>
<td>crs</td>
<td>Malta</td>
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<td>0.354</td>
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<td>crs</td>
<td>Portugal</td>
</tr>
<tr>
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<td>irs</td>
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</tr>
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<td>Italy</td>
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</table>

*irs = increasing returns to scale*
*drs = decreasing returns to scale*
*crs = constant returns to scale*
For quantifying the results obtained by DEA, two variables were introduced in the regression analysis, which represents the operational circumstances: one for the airspace size and one for the degree of sectorization. The results show a negative influence of the size of airspace to the efficiency values. Furthermore, there is a positive correlation between the number of sectors and efficiency. Both variables not only support the DEA results but also show a very high statistical significance.

The results of both, DEA and Regression Analysis, led to the assumption that in some cases the problems (e.g. high administrative burdens) exceed the benefits (e.g. reduction of coordination workload) of large air space blocks. Sensitivity analyses demonstrate the stability of the results, using several input and output factors. Despite the use of alternative inputs and outputs, the results of [11] were approved by [12] and [1].

Understanding system behavior presumes to understand the smallest units of the system as well as the influence on system's changes and interrelations. In ANSP context, these units were represented by the sectors. Since the data collection does not cover this operational level, an investigation was performed on sector group level. In prospective studies, these efforts will include the FABEC members; however, in preparation the methodology was tested on data provided by the German air traffic control DFS.
The investigation led to appropriate and plausible results. Especially approach and upper air space units achieve high degrees in technical efficiency. The traffic determinants of upper air spaces are high speeds, large amounts of traffic causing a large number of service units. Moreover, it can be assumed that the complexity of the air space is not as high as an Approach or lower airspace DMUs. The airspace characteristics of the approach units on the other hand are represented by a constant and high amount of traffic.

Figure 7 illustrates the average technical efficiency calculated by application of DEA. Due to structural changes and the periodical boundary (years 2004 – 2013), the investigation only includes sector groups existing over the entire time period. The approach units are colored with a green tip, upper airspace units with red and units of lower airspace with blue.

Figure 7: DEA Results on Sector Group Level

![Bar chart showing average technical efficiency for different sector groups]

Figure 8: Economic growth rates of total factor productivity

![Line chart showing growth rate of total factor productivity from 2005 to 2013]
The results clarify the coherency between demand and efficiency. Structural changes were observable as well as exogenous effects like economy crisis (blue arrow) or natural phenomena, e.g. volcanic eruption (figure 8). Finally, the results proved the applicability of the methodology on sector group level.

V. Innovative Benchmarking Scheme

The results discussed in Chapter IV proved the applicability of the multidimensional methodology on ANSP-related benchmarking efforts. In addition to the rudimentary analyses of ACE- and PRR-reports, DLR German Aerospace Center in cooperation with FABEC will introduce an innovative Benchmarking process for ANSP Assessment. Based on the results of previous studies as discussed for FAB-efficiency, the application of a modular scheme was proposed following a three step framework (figure 9).

In the first step, productivity and efficiency will be calculated. Based on defined input-output-correlations (e.g. KPAs and KPIs) to be analysed, the ATM performance of the assessed entities will be reviewed and analysed.

In the second step, there will be a root cause analysis, e.g. by application of regression analysis. Factors potentially influencing ATM performance will be identified and divided into those that are under control of ANSPs (endogenous factors) and those that are not (exogenous factors).
In the last step, it will be checked how these findings could be transferred to other operational units. On the basis of the endogenous influencing factors identified in step 2, those that are transferable to other entities will be highlighted to derive best practises for improving performance.

The three step framework is expended by three modules, which implement the potential improvements identified regarding to the previous Eurocontrol reports. These reports are based on PRU-data, whose acquisition process is regarded critically by some ANSPs. In consequence, the development of new data sources is required.

An efficiency benchmarking on a high operational level, e.g. ANSP level, consist of a cross-section of low level subsections. Analysing these subsections will bring a higher benefit for efficiency research of Air Navigation Services. One milestone of the study is represented by the application of three-step-framework on a benchmarking analysis of sector groups in FABEC context. In a further milestone, the results will be used to compare parts of the North American air traffic control (FAA) with FABEC.

VI. Conclusions

Economic studies demonstrate the enormous importance of air transport in the world. During the last century a strong and growing industry has developed, in which air transport based manufacturers and service providers accounted for about 3.4% of the world gross domestic product [13].

Based on the current official reports published by EUROCONTROL, there can be identified several potential improvements regarding methodology and information about efficiency enhancing and impairing factors. The aim of this research is to reliably assess the performance of European air traffic control companies and quantifying the reasons for possible inefficiencies.

The application of a multidimensional methodology led to appropriate results, regarding the impact of a FAB structure on European ANSP efficiency as well as on sector group level. In that case, there are significant indications against the consolidation of air spaces, especially for ANS providers which work under constant or decreasing returns to scale. The used methodology provides stable results. Therefore, the methodology is considered to be suitable for further research.

Based on this knowledge, a modular approach is introduced by DLR and FABEC which adopts a three-step framework. The modules represent additional approaches to existing assessment procedures: A multi-dimensional methodology is introduced; more operational levels will be analyzed and new data sources are included. By applying this scheme all identified potential improvements are covered.
References


