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EUROPEAN AIR NAVIGATION SERVICE PROVIDERS' EFFICIENCY EVALUATION THROUGH DATA ENVELOPMENT ANALYSIS (DEA)

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Abstract

This paper presents a benchmarking analysis of the efficiency and productivity of the air navigation service providers in Europe.

Its aim is to determine the relative position of each air navigation service provider in terms of efficiency, the potential for achieving specific performance targets, and how close or far each organization is from the optimal efficiency level determined by the most efficient amongst their peers.

The study is based on Data Envelopment Analysis (DEA), a nonparametric method extended in operations research and economics for the estimation of production frontiers, that is used to empirically measure productive efficiency of Decision Making Units (or DMUs).

1 General Introduction

One of the last measures undertaken within the framework of the Single European Sky program has been the development of a performance scheme for air navigation services and network functions [1].

The performance scheme should contribute to the sustainable development of the air transport system by improving the overall efficiency of air navigation services across the key performance areas of safety, environment, capacity and cost-efficiency.

The performance scheme should provide indicators and binding targets in all key performance areas; and it should also provide performance plans describing the measures, such as incentive schemes, aimed at stakeholders to improve performance at all levels.

Identical targets have been set for all air navigation service providers, regardless of the starting point of each provider or their relative inefficiencies. It may happen that the effort required by one company to achieve the targets is tiny in proportion to its ability; while for other companies achieving the targets under time and economic constraints may be virtually unattainable.

It is therefore necessary to perform a benchmarking of the efficiency and productivity of the European Air Navigation Service Providers to determine their potential to achieve those specific performance targets.

2 Methodology: Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a class of non parametric models that have been used to evaluate the efficiency and the performance of a set of peer entities called Decision Making Units (DMUs), which convert multiple inputs into multiple outputs.

It was first introduced in literature in 1978 by Charnes, Cooper and Rhodes [2]. Since its introduction, this methodology has proved particularly adept at uncovering relationships that remain hidden from other methodologies; it doesn't require explicit specification of functional relations between inputs and outputs (as in regression approaches); it can include multiple inputs and multiple outputs; it doesn't require "a priori" weights (as in index number approaches); and it has been successfully applied in a wide range of fields. [3,4,5].]

Relative efficiency in DEA accords with the following definition:

Definition 1.1 (Efficiency – Extended Pareto-Koopmans Definition): *Full (100%) efficiency is attained by any DMU if and only if none of its inputs or outputs can be improved without worsening some of its other inputs or outputs.*

Let's assume that there are n DMUs or ANSPs (Air Navigation Service Providers) to be evaluated. Each DMU consumes varying amounts of m different inputs to produce s different outputs. Specifically, DMUj consumes amount xij of input i and produces amount yrj of output r. We assume that xij >0 and yrj ≥0 and further assume that each DMU has at least one positive input and one positive output value.

The ratio of outputs to inputs is used to measure the relative efficiency of the DMUj=DMU0 to be evaluated relative to the ratios of all of the j = 1, 2, …, n .

We can interpret the situation (for each DMU) as that of a single 'virtual' output and 'virtual' input. For a particular DMU the ratio of this single virtual output to single virtual input provides a measure of efficiency that is a function of the multipliers. This ratio, which is to be maximized, forms the objective function for the particular DMU being evaluated.

The mathematical programming problem may thus be stated as:

$$max\ h_0(u,v) = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \qquad (1)$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \forall j = 1, \dots, n \qquad (2)$$

$$U_r, V_i \geq 0 \qquad (3)$$

for all *i* and *r*

where:

- The variables are the u_r's and the v_i's and the y_{ro}'s and x_{io}'s are the observed output and input values, respectively, of DMU_o , the *DMU* to be evaluated.
- The set of normalizing constraints (one for each *DMU*) reflects the condition that the virtual output to virtual input ratio of every *DMU*, including DMU_j=DMU_0 must be less than or equal to unity.

3 Data used in the analysis

In 2010, EUROCONTROL, the European Agency for the Safety of Air Navigation, was designated by the European Commission as the Performance Review Body (PRB) of the Single European Sky (SES) with the purpose of assisting the European Commission in the implementation of the performance scheme and to assist the National Supervisory Authorities (NSAs) on request. Two of the PRB's key tasks are:

- **advising** the European Commission in setting EU-wide performance targets and assessing National / Functional Airspace Block (FAB) Performance Plans.
- **monitoring** the performance of the system in four Key Performance Areas: Safety, Capacity, Environment and Cost-Efficiency.

This designation is the recognition of Eurocontrol PRU's 12 years' experience and expertise in monitoring performance, benchmarking and identifying reasons for differences in ANSPs' performance levels, and setting high-level quantitative targets for improvement in a number of key performance areas.

The data used in this study were drawn from information provided by 35 European ANSPs as part of their annual mandatory performance report to EUROCONTROL PRC/PRU (Performance Review Commission/Performance Review Unit).

The PRU or Performance Review Unit is a Eurocontrol unit responsible for monitoring and reviewing the performance of the European ANS System. It supports the effective management of European ANS through target-setting and the establishment of a transparent and independent performance review system which addresses all aspects of ANS, including policy and planning, safety management at and around airports and in the airspace, as well as financial and economic aspects of services rendered. For several years now the PRU has been actively involved in evaluating the performance of Air Navigation Services Providers (ANSPs) in Europe. [6]

Inputs	**Costs**	MET costs Payment to national government EUROCONTROL costs Irrecoverable value added tax (VAT) Costs for delegation of services Costs for other services provided
	ATM/CNS provision costs	Staff costs Direct operating costs Exceptional items Depreciation Cost of capital
	Staff cost	Total staff ATCOs in OPS ATCOs' hours on duty Staff costs for ATCOs in OPS
Outputs	**ACCs operational data**	Sum of flight-hours controlled by: ACCs ATCOs in OPS ATCOs' hours on duty Number of sectors Hours/sector Sum of sector-hours
	En-Route output data	Total IFR flights controlled by the ANSP Total flight-hours controlled by ANSP ATCOs in OPS (ACC) ATCOs in OPS (APPs+TWRs) Total number of sectors (ACC)5 Sum of sector-hours (ACC)
	Revenues	Income from charges Other revenues Over/under recovery

Table 1. Air Navigation Service Provider Data used in the study

The Table 1 summarizes the most significant data used in this analysis. The sample contains annual data from the 35 European ANSPs during the period from 2001 to 2011 and includes information on costs, inputs, outputs, traffic variability and complexity characteristics. A detailed description of the data, including all checks and validations, can be found at the ATM Cost-Effectiveness (ACE) Benchmarking Reports, prepared by the Performance Review Unit (PRU) with the ACE Working Group. [7].

ANSPs in the sample vary substantially depending on the size of the controlled airspace, the volume and characteristics of traffic served and its governance structure. Despite this heterogeneity, annual data provides enough information on a comparable basis, to allow a fair and robust comparative analysis of the effectiveness of the ANSP.

The correlation coefficients between the various indicators were used to identify variables that will be taken as inputs and outputs of the DEA model, taking care not to include variables that reflect the same effect

Specific aspects of the data are discussed below: Inputs, outputs, the size of the network and traffic characteristics

3.1 Inputs

The main input variables of the model are related to costs and staff. Data shows that personnel costs are the largest share of total ATM / CNS costs. Direct operating costs are the second largest contributor to the total cost. Depreciation and cost of capital are the smallest components, on average, despite representing a greater proportion of the costs of some individual ANSP.

It may also be noted that five suppliers (DSNA, DFS, Aena, NATS and ENAV) support 56% of the total costs of the provision of CNS / ATM service at European level while they share of traffic is 52%. This result contrasts with the expectation of increasing returns to scale (the performance of the largest ANSP could benefit from its larger size). Under the regime of full cost recovery that applies to most of the ANSP there is little incentive to maximize the effects of scale, hence the difficulty to observe them. Additionally, largest ANSP tend to develop bespoke automated systems, which may be more expensive than a commercial solution (COTS).

Other important variables to be considered are those that have to do with productivity, including productivity per Controller working hour (ATCO-hour productivity-) defined as the number of flight hours handled by each ATCO hour. This indicator is influenced by the productivity of the sector (reflecting whether the number of sectors is optimal for the volume and pattern of traffic), the sector staffing, and ATCO productivity (reflecting, for example, efficiency and flexibility of ATCO rostering). Arguably the ATCO-hour productivity is the efficiency with which an ANSP deploys and uses its staff of ATCOs. In 2011, the Pan-European system as a whole managed 0.80 hours of composed flight time per each of ATCO working hour.

ATCO employment costs are also relevant. They reflect the outcome of negotiations over wages, the working practices under the control of management; and also local economic conditions that are beyond the control of management. Average ATCOs unit labour in the pan-European system were 101 €per ATCO hour, although there is a wide range of labour costs for the ATCO time between different ANSP. Equally important will be the support costs and in particular the ratio of total ATM / CNS provision costs to ATCO employment costs. Support costs can be divided into four components that provide a greater understanding of their nature:

- Employment costs for non ATCO in OPS accounts for air traffic controllers in other tasks such as training, technical support and management and administrative jobs (46.4% of supposed support costs);
- Operating costs not related to personnel expenses mainly include energy, communications, contracted services, rents, insurance and taxes (25.7% of support costs);
- Exceptional costs (1.1% of support costs), and
- Costs related to capital, including financial costs and depreciation on capital employed (26.8% of support costs).

ATCO Labour costs per composed flight hour are the result of the combination of the above two components: ATCO-hour productivity and ATCO-hour labour costs. All other things being equal, lower ATCO labour costs per unit of production will contribute to greater financial returns. An ANSP can have high ATCO labour costs per hour but if their ATCOs are highly productive, it will have lower labour costs per composed hour . This is the case of the ANSP as MUAC, showing labour costs per ATCO-hour above the European flight average, but ATCO labour costs per composite flight hour below the European average. Some ANSPs such as Belgocontrol combined with higher ATCO labour costs with lower ATCO productivity, resulting in higher ATCO labour costs per unit of production. Other ANSPs such as Naviair have both increased productivity and lower ATCO hours labour costs.

3.2 Outputs The outputs generated by the air navigation services providers can be measured in different units as flight hours or distance flown for on-route operations, or number of IFR and VFR movement for operations at airports. For example, in 2011, operational units controlled by European ATC services amounted to 14.5 million hours of flight with over a total distance flown of 10,092,000 miles. At the same time, TWR units handled 15.4 million IFR movements and 3.3 million VFR movements.

In this study the approach adopted in the ATM Cost-Effectiveness (ACE) Benchmarking Reports 2001 to 2004 has been followed. A composite measure of productivity is defined as the number of composite flight hours controlled. This indicator is a weighted average of en route flight hours controlled and the number of IFR airport movements controlled. The weights used in the calculation reflects the relative importance (in monetary terms) of the on route and terminal area services on average for all European ANSPs, at the base of the total costs.

$$\textit{Output = Composite flight hours controlled= en-route flight hours + 0.26 x IFR airport movements} \quad (4)$$

According to this definition, the total number of composed flight hours for pan-European system in 2011 was 18.5millones.

It should be noted that the production, as discussed in this study, is a measure of demand satisfied rather than capacity provided. Where demand is much lower than expected, production values can be quite different. It can be argued that provided planned capacity may be a better and more direct measure of what actually is produced by the ANSPs. However, if an ANSP systematically would provide excess capacity it should rightly be labelled as inefficient. Using a measure of the satisfied demand as production indicator captures this source of inefficiency.

Other key features for the efficiency of the ANSPs are the variability and complexity of the traffic. The measure of the temporal variability of controlled air traffic is defined as the ratio between peak week traffic and average week traffic. If traffic has a high variability resources may be underutilized (inefficiency in the allocation). The variability of the traffic demand therefore has an impact on productivity, cost effectiveness, quality of service and predictability of the operations.

On the other hand the "complexity of traffic" is a term widely used in relation to the air traffic management although there is no single measure that captures it rightly. Traffic complexity can be characterized from two indicators :

- "**Adjusted density**": a measure of the intensity of interactions suffered by a flight in a given airspace volume (FIR, ACC, sector,...l) and is defined in terms of minutes of interaction between aircraft per flying hour
- "**Structural complexity**": an indicator that takes into account traffic interactions can be structurally more complex in some areas than in others. It is defined as the combination of three factors: differences in vertical orientation (ascending and descending routes), differences in horizontal orientation (crossing routes) and differences in speeds (traffic with different speeds).

A plus of these indicators is that they are independent. Traffic in one area may be dense, but structurally simple. Also, traffic can be structurally complex but sparse. Moreover, the two impacts are multiplicative, the overall rating of the complexity of the traffic can calculated as the product of the structural complexity and adjusted density. Complexity can have a positive effect on the performance of the ANSP, since higher density may contribute to better use of resources and more effective use of economies of scale. But it can also have a negative effect because a greater structural complexity imply greater ATC workload and therefore a more complex ATM system for the same volume of traffic.

There are a number of factors affecting aircraft operations and contributing to the quality of service provided to users of airspace by an ANSP. These aspects should be considered as outputs of the service provider. These include ATFM delays , due to both en route and airport congestion; holding in the air (although these are mostly a result of airport restrictions); horizontal flight efficiency; extending length of flight; vertical flight efficiency and the resulting deviation from the optimum vertical flight profile. However due to lack of data only the first of these factors has been considered in the study .

Another factor to consider is the size of the network, which can be quantified based on the following indicators:

- the average flight transit time of, which is obtained by dividing the number of flight hours by the number of flights within a given air space;
- the size (in km) and the volume of controlled airspace in which ANSPs are responsible for providing ATC service

4 Results and discussion

DEA is a method to compare efficiencies between producing entities with similar characteristics, to determine those that are more efficient compared to the group and calculate performance levels to be achieved by the inefficient ones to become efficient. The analysis is performed considering efficiency as a measure of the relationship between the results and the resources used to generate them.

This study has made an initial assessment of the ANSP efficiency considering 4 possible models approach.

- Model 1 Output oriented Variable Returns to Scale (VRS) Model
- Model 2 Output oriented Constant Returns to Scale (CRS) Model

- Model 3 Input oriented Variable Returns to Scale (aditive)
- Model 4 Input oriented Constant Returns to scales (aditive)

In the output-oriented models the projected point could to be achieved by the evaluated inefficient DMUs is calculated so that the proportional increase in exits is maximum possible without increasing the level of inputs. The input oriented models attempt to minimize the consumption of inputs for a given level of production.

Consideration of variable or constant returns to scale is introduced in the study because a priori there is no evidence to say that there are variables or constant returns to scale.

A general analysis of the results is presented here after, although it should be noted that this is only a preliminary study.

Table 2 presents observed values for all ANPS and distance to the bound of technical inefficiency of the entities/DMUs classified as inefficient, which corresponds to the inefficiency on each variable for each model. Based on this it can be infered which variables are the weaknesses of each entity and what is potential for improvement of each entity.

On models 1 and 3 with variable return to scale, 15 out of the 35 analyzed entities make up the envelope that defines the efficiency, and consequently 20 entities were identified as inefficient, i.e. they could generate more output with existing resources, and vice versa produce their current output with fewer resources. ANSPs that served as reference for the greatest number of their peers were MUAC, DCAC NATA Albania and Cyprus. These should be analyzed internally to identify the practices that allow them to have high performance.

On models 2 and 4 with constant returns to scale, 7 out of the 35 companies analyzed make up the envelope that defines the efficiency, therefore 28 entities were identified as inefficient. ANSPs that served as reference for the greatest number of their peers were the same as in the other two models.

	Efficiency score			
	Output oriented		**Input oriented**	
ANPS	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Aena	100	42,99	100	42,99
ANS CR	56,82	55,72	60,94	55,72
ARMATS	100	76,29	100	76,29
Austro Control	66,4	60,24	61,05	60,24
Avinor	58,5	57,28	59,79	57,28
Belgocontrol	30,04	38,64	47,43	38,64
BULATSA	68,21	62,98	65,04	62,98
Croatia Control	66,3	58,26	63,23	58,26
DCAC Cyprus	100	100	100	100
DFS	100	38,67	100	38,67
DHMİ	100	76,54	100	76,54
DSNA	100	46,22	100	46,22
EANS	100	100	100	100
ENAV+ITAF	100	53,8	100	53,8
Finavia	52,02	50,95	56,71	50,95
HCAA	100	100	100	100
HungaroControl	69,19	65,38	65,97	65,38
IAA	93,6	75,92	90,84	75,92
LFV	96,63	89,4	95,9	89,4
LGS	93,97	89,62	91,67	89,62
LPS	72,66	72,14	80,4	72,14
LVNL	43,04	41,65	52,78	41,65
MATS	100	100	100	100
M-NAV	100	100	100	100
MoldATSA	100	71,43	100	71,43
MUAC	100	100	100	100
NATA Albania	100	100	100	100
NATS	100	51,98	100	51,98
NAV Portugal	77,27	74,12	80,69	74,12
NAVIAIR	58,43	56,86	59,6	56,86
Oro Navigacija	82,55	82,27	83,48	82,27
PANSA	66,96	66,51	66,73	66,51
ROMATSA	55,45	51,96	53,23	51,96
Skyguide	65,54	61,9	70,81	61,9
Slovenia	100	83,25	100	83,25
SMATSA	85,89	70,18	82,84	70,18

Table 2. Data envelop models results

Regarding the choice between models, it must be emphasized that all of four provided important guidelines on how an ANSP may improve its efficiency by increasing its level of outputs or reducing its level of inputs. The decision on which alternative to choose should be based on market requirements and the best strategy for improving long-term sustainability. It should be noted that this analysis is a comparative type, so it cannot be said that DMUS classified as efficient have no further potential for improvement. For this reason, and also to assess the progress of DMUs which are classified as inefficient, it this analysis should be performed periodically.

5 Conclusions

The DEA methodology has proved to be a positive and suitable way to analyse Air Navigation Service Providers companies which use in their production process multiple inputs and produce various outputs (capacity, safety, delay, etc ...)

The results have allowed to analyze the various providers of air navigation services in Europe in terms of its relative efficiency and determine which strategies and actions should be undertaken by each one of them to reach an optimum level of efficiency. This comparative analysis facilitates to determine which providers have a greater margin of efficiency improvement to achieve the objectives set by the performance evaluation framework of the SES as well as determine which providers are working more efficiently.

Additionally, the application of the method has offered a lot of particularized information about each company that can be used to establish practice guidelines in order to improve the performance of inefficient units.

In conclusion, the study has revealed that the Data Envelopment Analysis is appropriate to analyze the efficiency of the public air transport sector , in particular in the provision of air navigation services, even though this sector has been resistant to other methods, due to the unknown and often complex nature of the relationships between multiple inputs and outputs that can bay to day running of these companies.

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