EVALUATING THE PERFORMANCE OF AIR CONTROL CENTERS

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Abstract

A benchmark analysis of Air Control Centres (ACCs) in Europe is performed based on a Data Envelopment Analysis (DEA). Relying on a broad literature survey (cf. [12]), the main characteristics of the ACCs activity are highlighted: capacity and human factors, assets, traffic, cost-effectiveness, efficiency and safety. Basic categories of performance objectives that define Air Traffic Service (ATS) quality to the Aircraft Operators (AOs) are also introduced: delay, predictability, punctuality, flexibility, access. The principal analysis run interests sixty-three Decision Making Units (DMUs), the European ACCs, and takes into account five variables: the total number of Air Traffic Controllers (ATCOs), the total number of en-route delay minutes, the total number of delayed flights, the total number of Instrumental Flight Rules (IFR) km controlled, and the total number of vertical movements. The analysis is input-oriented and assumes variable returns to scale. Efficiency scores for each ACC are obtained and the numerical results are eventually discussed and analysed.

Introduction

Since the late 1980s (the first European «Aviation Liberalization Package» was approved in 1987) a wave of reforms has transformed the operating environment of the Air Traffic Management (ATM) companies. The ATM system itself is undergoing an evolution. Facing a stronger competitive environment in even more congested markets, a key objective for authorities is to improve the efficiency and responsiveness to market needs of the ATM procedures. In such sense, among other measures (as the reduction of vertical separation minima), several countries are preparing, or at least considering, the privatisation of their air traffic service providers [19] to achieve the efficiency objective by enhancing access to capital and human resources with a market-oriented approach. In this context, the evaluation of the Air Control Centers (ACCs) is an area of greatest interest, not only from the point of view of their economic efficiency, but also considering their global performance, e.g., considering the quality of the service they offer.

The aim of this paper is to study performance analyses and benchmarking techniques applicable to ACCs in Europe, with particular emphasis to potentials of DEA.

DEA is a non parametric evaluation model, which assesses the efficiency of a set of comparable DMUs. It takes into account input and output variables and assesses the relative efficiency of the DMUs. For each DMU, data are weighted by the coefficients that maximize its performance, i.e., the output/input ratio, when compared to the performance of all the other DMUs [3], [4]. In this way, DEA produces for each DMU its relative efficiency, its benchmarks and the targets for performance improvement.

The Benchmark Analysis

The main characteristics of the air transportation industry and of the ACCs activity are the heterogeneous nature of the output, the indivisibility in production (the opening of a sector by an ACC satisfies the demand of several users simultaneously), a not necessarily continuous production function, and capital expenditures not linear with the output (typically large sums are required for capacity investments) [5], [13]. As a consequence, the factors to be considered in the assessment of ACCs are not homogeneous nor univocally identified. In the following, the most relevant of them are analysed, according to the available literature (for a more extensive review, cf. [12]).

Capacity and Human Resources

In the ATM field there is not a unique measure for the output; the service can be perceived, e.g., either as a distance flown under control (a proxy for the actually used capacity) or as the actual sector capacity (the maximum number of flights a team of ATCOs can cope with, a proxy for the provided capacity). The absence of measurement for the provided capacity and the difficulty to define the concept of capacity itself, lead to focus on the number of flights or kilometres controlled.

According to [1], capacity can be increased, e.g., through a sensible policy of ATCOs, the opening of new sectors (considering the limits on the activity of coordination of the different sectors), and a centrally harmonized policy of cooperation among the ACCs. It could be possible, moreover, to evaluate and benchmark the recruitment and personnel policy of the ACCs.

As far as productive efficiency is concerned, in [11], staff productivity is measured by the capacity provided per staff member employed or per hour worked: some metrics are the total ATCO hours on duty in operations (OPS) per number of ATCOs in OPS; the sector hours per number of en-route ATCOs in OPS; and the flight hours controlled per number of ATCOs in OPS.

In [18], the EU candidate states are assessed. The en-route labor productivity is measured by flight-hours or flight-km controllable. By comparing the flight-km controlled per ATCO-hour in OPS, there is a huge variation among the states, with a factor of over four between the greatest and the smallest. The flight-hours per sector-hour indicator shows that, averaged over the period, a sector in each of the states controls somewhere between a little over four ACs in the Czech Republic and a little over one in Lithuania. Probably, this indicator is low for areas with few sectors, since they have not the same flexibility to reduce staffing at night.

Productivity concepts and relative indicators are given also in [5] and [13]: productivity of ATCOs (km controlled per number of en-route ATCOs; number of movements per number of en-route ATCOs; hours controlled per number of en-route ATCOs), productivity of other skilled staff associated with en-route control, productivity of total labour.

In [2], ATCOs productivity is approached from either an input perspective (as number of ATCOs per flights handled) or an output perspective (as hours in position). ATCOs unit costs, when weighted with comparative price level indices, show significant differences across providers up to a factor of five, without any clear relationship with the country cost of living. Rather, this result can be seen as indicating the large variation in controllers professional and social status in each provider country, and therefore invalidates the notion that ATCOs unit costs are related to the provider country cost of living and could impede significantly the mobility of controllers from one provider to another in the future.

In [18], as far as the employment costs of ATCOs in the candidate states is concerned, the ratio of ATCO wages to GDP per capita gives for the most part a fairly narrow range of around 3 to around 7, however, in one country it is 2.4 and another over 18.

According to these findings, it would be preferable not to take into account the wages and the cost of living in the different countries in the benchmarking analysis, but to simply consider the number of ATCOs of the different ACCs in order to avoid any misunderstanding about the data and their comparison due to administrative and legal differences among the countries.

An illustrative benchmark could be the comparison between the contracted hours and those that controllers actually work. Among the candidate states that have the highest contractual hours, two permit overtime; this can have an adverse effect, especially when combined with lengthy shift periods (some states have indicated that they employ 11 to 12 hours single shifts, matched by equal off-duty periods). Particularly important is the amount of time ATCOs actually spend controlling in a single session. A controller workload can vary markedly from low to very high intensity, however, there should be a maximum time that controllers are required to spend actually at the console without a break. The above considerations can follow the benchmarking and efficiency analysis and can be done separately for each ACC in order to add some explanatory power to the results obtained.

In [2], the analysis of staffing across providers shows two clear groups: one consisting of larger providers with over 1,500 employees, and one consisting of the smaller providers. For all Air Navigation Service Providers (ANSPs) there is significant variation in the amount of resources used in various staff categories (i.e., relative proportions of technical staff, ATCOs on duty, and administrative staff). Nevertheless, a strong relationship exists between both total staffing, total ATCOs in OPS and IFR flights, and total staffing, total ATCOs in OPS and the number of sectors handled.

As far as productivity is concerned, there is a large variation in manning per sector in the working practices, with an average of 17.5 controllers per sector.

Assets

As far as the other major input of the ACCs activity is concerned, in [11], asset productivity is measured as the capacity provided per unit value of the fixed asset base. Some measures are sector hours/ Net Book Value (NBV) fixed assets in operation; number of sectors/NBV fixed assets in operation; km controlled/NBV fixed assets in operation; flight hours controlled/NBV fixed assets in operation.

In [18], the asset productivity is measured as sector-hours (or flight-hours controllable, if available) per unit value of asset, and flight-hours controlled per unit value of assets. The en-route flight-km controlled per €-worth of fixed assets (NBV) shows a remarkable variation among the candidate states, with a factor of twenty between the lowest, where a €-worth of assets is required to control 0.23 flight-km, and the highest, where it controls nearly 15 flight-km. This could be related to the age of systems.

In [5] and [13], the productivity of capital equipment is measured as km controlled per value of fixed assets, number of movements per value of fixed assets and hours controlled per value of fixed assets. Moreover, differences exist in the allocation of costs between en-route and terminal ANS: apparently high en-route costs may in some cases simply indicate that the share of total ANS costs passed to en-route is above the average. Part of the cost difference can be explained also by the complexity of the traffic; it is therefore important to appreciate whether the observed unit cost differences are justified by using objective measures of traffic characteristics.

Traffic

The traffic management is an important issue. In [15], the trend of the traffic growth (number of flights), actual and forecast, is considered. The increase in traffic volume (measured by the ACC movements or by the distance flown), is a good measure of ACC load. IFR flights, traffic volume (measured as total IFR distance flown), and the average distance flown are of interest.

Moreover, the quality of traffic managed is a relevant subject of investigation for the assessment of the ACCs efficiency. It would be interesting to understand how the resources (human and technical) are able to manage different flight profiles, i.e., over-flight vs. vertical traffic. The management of vertical traffic absorbs indeed a greater amount of resources with respect to the management of over-flight traffic; it is therefore important to consider not only the total number of movements or kilometres managed as an output of the activity of an ACC, but also the number of kilometres relative either to the over-flight traffic or to the vertical traffic. According to [18], the operational complexity can be related to the density, function of the concentration and the volume of traffic (number of IFR flight-km controlled per year per km^2 of airspace), and the number of vertical levels per movement. Economies of density indicate a higher rate of capacity utilization and a lower unit cost, diseconomies of density indicate a higher complexity and more expensive operational system and traffic.

Also in [5] and [13], the percentage of over-flight traffic in the country is considered: since it generates less workload than cruising traffic, it could capture the activity complexity. By the way, the number of flight level crossed per km and the airport movements per km appear to better represent the vertical evolutions. It should be also noted that the two indicators are strictly correlated, as each airport movement is associated with a climbing or descending phase.

Some results of the analyses in [5] and [13] show how an increase in traffic yields an increase in the number of km controlled and in the density of traffic. The model predicts that a 10% increase in traffic generates a 13% increase in total costs. As traffic increases, both the kilometres controlled and the density of traffic increase. Although greater traffic density allows for a better exploitation of fixed inputs, it also increases the workload and thus the costs. The model in [5] suggests that it is the latter effect that dominates. On the other hand, the model predicts that there is a cost advantage in controlling flights over long distances. An increase of 10% in the average controlled distance decreases total costs by some 3%, all other conditions being equal. This result indicates slight economies of scale in respect of FIR size or route length controlled. The model suggests also that if the percentage of over-flights increases by 10%, for a given number of flights and kilometres controlled, total costs would decrease by some 2.4%.

The composition of IFR flights in the EU candidate states is considered [18]. The traffic composition is different than in most EU countries, with typically a large proportion of over-flights. It might be expected that the lower complexity of flights would lead to lower unit costs than in EU states, but no correlation has been demonstrated through this detailed benchmark. The number of domestic flights is generally very low; they only make a significant contribution in the countries with the largest area: Turkey, Poland and Romania (with a minimum surface of about 250,000 km^2).

According to [2], a general trend shows that traffic increases in a steeper way than the number of sectors as one moves from the European peripheral providers towards the core European area.

Cost-effectiveness

As far as the cost-effectiveness is concerned, in [18] the measures of cost effectiveness comprise total en-route costs per en-route km controlled, en-route capital costs per en-route km controlled, en-route operating costs per en-route km controlled. This indicator results highly correlated with the unit rate for route charging. In the EU candidate states, the en-route costs can be approximated as 600 millions € for 1 billion IFR flight km, giving an average cost per km of 0.6 €; the European average for 2001 has been estimated by the PRU as 0.75 € for 6.3 billion IFR km. Aside from Bulgaria, Poland and Slovakia, the candidate states are below the European average cost per IFR km for 2001; by the way, there is no agreed notion of the target level of en-route charges, although the US compares favourably at around 0.4 € per km.

In [15], the evolution of en-route costs, traffic (in kilometres) and average cost per km is given from 1990. Unit costs are obtained by dividing the en-route costs (including EUROCONTROL costs) by the number of km computed by the Central Route Charging Office (CRCO). This is considered as a better measure of ATM performance than the unit rate used for charging purposes: the value for a given year is not affected by over or under recovery in the previous year and the measure is not influenced by the aircraft weight.

The breakdown of total en-route costs per category for 1998, 1999 and 2000 is:

- staff costs: 51%, 54.5% and 55.1%,
- operating costs: 26%, 24.2% and 24.2%,
- gross margin (or operating profit): 22%, 21.3% and 20.7%; it is divided in depreciation 15%, 14.7% and 14.3% of the total national cost bases (equivalent for year 1999 to 567 million €), and in interest 7%, 6.6% and 6.4% of the total national cost bases (equivalent for year 1999 to 253 million €).

Also Meteorological (MET) costs are considered in [18]. Large variation is found in MET costs: MET costs per 1000 en-route flight-km are considered. States costs vary from € 1.5 to nearly € 70; this is due to the fact that ANSPs are normally required to purchase services from a national monopoly provider.

Efficiency

The INTEGRA studies (refer to [8] and [9]), consider the efficiency of the ATM system. The sum of the minimum duration of flight in minutes has been validated as the primary ATM output. The discrete flight efficiency, set to a requested routing in terms of flight duration and optimum Flight Level (FL) with a minimum of FL changes, is investigated. It is the ability of the ATM system to allow a user to adopt its preferred 4D-trajectory profile; the requested trajectory and a calculated difference between the actual trajectory and the requested trajectory for specific costs are taken into account. The productivity factors identified are the capital (e.g., equipment, ground property, radar), the labour (ATCOs, technicians, engineers), and the operating (e.g., electricity, fuel, engine maintenance, route charges). As outputs, among others, the over-flight time is considered. As inputs, the ideal and actual flight times, the additional airport and route-charges cost, the additional maintenance and crew cost, and the additional cost due to delay.

In [1], the efficiency metric compares the planned or actual flight path trajectory (including route and altitude) to an optimum baseline (non scheduled baseline) path trajectory (or flight duration).

An initial flight efficiency indicator is the average flight inefficiency. Horizontal flight inefficiency in percentage (vertical flight profiles are not yet considered) for a particular flight is defined as the difference between actual and optimum flight path (unconstrained by ATM routes) divided by the optimum flight path length. Average flight inefficiency for the core area of Europe varies between 10-12% for very short flights (under 400 km) and 8% for routes between 400 and 1000 km.

From available information, it appears that horizontal flight path extension induces between 2% and 9% additional fuel burn for en-route portion of flights. This translates into direct additional costs to users and into additional emissions. Terminal phases of the flight can add to this figure (holding patterns, non-optimal climb/descent profiles, and extended low-altitude flying).

Within the framework of ACCs benchmarking, the guidelines for evaluating the ATM efficiency are very useful, even if not all the data required are at disposal both at an individual ACC level and at a nation level.

Safety

As far as safety is concerned, the INTEGRA studies identify two metrics: the likelihood of a safety event occurring during normal operations (propensity), and the extent to which the ATM system responds to a safety significant event without causing more such events (resilience).

Under the JAA Joint Safety Strategy Initiative (JSSI), seven focus areas have been identified: Near Controlled Flights Into Terrain (CFIT), approach and landing, loss of control, design related, weather, occupant safety and survivability, runway incursions.

The types of ATM incidents reported by ECAC states that have been investigated for years 1999 and initial 2000 are: separation minima infringements (975 and 704), unauthorized penetration of airspace (511 and 379), AC deviation from ATM clearance (e.g., level bust) (164 and 104), runway incursion (56 and 114), AC deviations from applicable published ATM procedures (30 and 18), inadequate separation (78 and 44), CFIT (6 and 1), runway excursion by AC (2 and 45), other types of incidents (82). It is to emphasize that one incident can be classified under multiple heading (e.g., a level bust can also result in inadequate separation).

At the moment, it is possible to separately consider the total number of accidents (which can be divided into "fatal", "hull loss" and "CFIT") and the total number of incidents (which can be divided into "*airprox*", "ground proximity report", "inadequate separations", "altitude deviations" and "Traffic Controlled Tower, TWY incursion"). The total number of accidents vary from 25 to 40 a year, fatal accidents from 2 to 15 a year, and total fatalities from 250 to 490 a year [17].

By the way, the safety issue is a very sensitive one and, moreover, very poor data exist. Therefore, it has been chosen to temporarily freeze this issue and not to take into account a variable relative to safety, e.g., the number of accidents, incidents, air proxes related to each ACC to be assessed.

Basic categories of performance objectives that define ATS quality to the AOs are outlined in the study *Airline Metric Concepts for Evaluating Air Traffic Service Performance* of the Air Traffic Service Performance Focus Group (ATSP FG) [1].

Delay

Delay has traditionally been used as the most direct measure of ATS performance. However, measuring delay against scheduled times in a congested system could become much less meaningful over time, because so much expected delay is inserted into the airlines block times to maintain operating integrity. Conceptually, delays should be measured by comparing actual flight times against optimum times (not against scheduled times) in order to assess the overall ATM system performance. Optimum time is defined by C/AFT as a time baseline that is not based on schedule. The development of a baseline optimum metric should include assumptions on basic performance constraints (e.g., runway occupancy time).

Predictability

As the variance of expected delay increases, it could become a very serious concern for airlines when developing and operating their schedules. Predictability metrics should be based on a comparison of the actual flight time to the scheduled flight time, since the scheduled flight time includes the amount of expected delay at a targeted dependability performance. Trends in change of the scheduled flight time (in minutes) could also be considered. Demand predictability is an essential element of the traffic planning process. While traffic forecasts have been fairly reliable at ECAC level, this has not always been the case at local level, especially for ANSPs with less traffic. ANSPs managing low traffic (less than 0.3 million flights) present a high traffic variability versus forecast (e.g., from –15% of Latvia to +144% of Slovenia); ANSPs managing medium traffic present an average traffic variability versus forecast (e.g., from –20% of Hungary to about +30% of the Netherlands); ANSPs managing large traffic (more than 1 million flights) present a low traffic variability versus forecast (e.g., from about +2% of Germany to +10% of Belgium-Luxembourg) [14].

As daily average Air Traffic Flow Management (ATFM) delay indicators are considered en-route ATFM delays (minutes); average ATFM delay (minutes/flight); the percentage of ATFM delays superior to 15 minutes.

It is possible to individuate the ACCs which represent the top bottlenecks of the air system. The total number of minutes of ATFM delay, the number of delayed flights, and the average delay per delayed flight are considered. Concerning this topic, it can be observed that it would also be possible to take into account different thresholds of delay: it would thus be possible to differentiate ACCs according to the number of delayed flights with a minimum delay (within, e.g., 5 or 10 minutes) or with a bigger delay (superior to 10 minutes, e.g.).

The number of over-deliveries and the number of lost ATFM slots can measure two key factors when examining the performance of ATFM system: the degree of protection against demand and the optimum use of available ATC capacity. Also unnecessary ATFM regulations, i.e., when demand never exceeds capacity, influence consistently the use of available capacity.

According to [18], among the candidate states the figures for 2001 of the average delay per flight ranges from 0 to 1.6498 minutes. Only Poland is over the optimum average delay per flight figure of 1 minute set by the Performance Review Commission (PRC). This implies that there is a generally over-capacity in the EU candidate states.

Since the opinion of the end users of ATS is of great importance, it is also interesting to report some findings of a study conducted by the EEC - PFE on the analysis of passengers delay [6].

Punctuality

Punctuality is a key attribute for the passengers. It is relevant to stress that arrival delays are quoted to be more important than departure delays (51% to 43%).

Flexibility

In [1], flexibility addresses how well the ATM system allows airlines for better operating dynamic decisions. As flexibility metric, the rate of ATS denials on ATS change requests could be considered.

Access

In [1], access metrics take into account both the ability to fly through a normally restricted area and how much advance notice of its availability is provided. Most of this value would be gained if availability is known when the airline is developing the operating schedule and making resource plans several months in advance.

Environment

As far as environment is concerned, the overall major generation of pollutants occurs in two phases of flight: cruise (57% of the fuel burnt in 2000) and climb (36% of the fuel burnt in 2000); descent, approach and take-off play a marginal role.

Investments

According to industry estimates, some 400 millions € on average is invested in ATM system every year. Investments in ATM R&D is in the order of 200 millions €; this corresponds to the 10% of ATM costs, which is low by industry standards. The remainder is mostly devoted to CNS and infrastructure, some 600 millions €.

European ATM R&D is presently highly scattered, with an average project size of 0.7 millions € and a multiplicity of sponsors.

Data set

The main areas of interest for a benchmarking of the ACCs have been outlined above. An exhaustive set of data has been given and motivated. This is a useful support for the choice of the data for the DEA. However, the lack of the data required is a critical issue. In the following the list of the variables chosen, according to the availability of the data, is given:

- National costs [Annexes to 15],
- Total assets [Annexes to 15],
- Total staff [Annexes to 15],
- Total ATCOs [Annexes to 15],
- Total number of flights [Annexes to 14],
- Number of over-flights [7],
- Number of vertical movements [7][1],
- Total minutes of delay [Annexes to 14],
- Total minutes of en-route delay [Annexes to 14],
- Total number of delayed flights [Annexes to 14],
- Total revenues [Annexes to 15],

[1] The number of national vertical movements consists of the sum of the international and domestic movements, i.e., of the sum of departures, arrivals, and two times the internals.

- Total en-route revenues [Annexes to 15],
- Number of IFR flights [Annexes to 15],
- Number of IFR kilometers [Annexes to 15],
- Size of controlled airspace (km^2) [Annexes to 15].

It is important to stress that not all the data are available at the ACC level for all the variables chosen. Only for some variables the data are available for each ACC; the variables are the *total number of flights*, the *total minutes of delay*, the *total minutes of en-route delay*, and the *total number of delayed flights*. For the other variables the data are available at national level; therefore, the data for the ACCs of each nation have been randomly generated (starting from the datum available for each nation).

The benchmark analysis in the following described is, therefore, an exercise and the result can not be referred to the European ACCs.

Comments on the variables

On the selected variables some comments have to be done. As a foreword, it is important to stress that in DEA an increase in an input variable worsens the efficiency of the evaluated unit, and, on the contrary, an increase in an output variable improves its efficiency.

Revenues and Costs

Therefore, as far as the ACCs revenues is concerned, it would not be correct to consider the variables *total revenues* and *en-route revenues* as outputs. In fact, since the ANSPs operate under a total costs recovery system, an increase in the revenues is the direct consequence of an increase in the national costs (by means of an increase in the unit rate of the route-charges formula of each nation); an increase in revenues, highlights then a loss of efficiency of the ANSP assessed, not an improvement. An increase in the unit rates (and then in the ANSPs revenues) could be justified only in the event of a better quality of the service offered. Since the ATS provision is operated in an off-the-market condition, and since considering the revenues as an output could yield to distortions and misunderstandings, it has been decided not to take into account neither the variables *total revenues* and *en-route revenues* nor the related proportional variable *national costs*.

Another relevant issue considers the fact that some variables are, on different degrees, out of the control of the ACCs. In the following, the controlled surface, the traffic and the delay are discussed.

Surface

The *controlled surface* is a given resource, an input on which the ACCs cannot decide. It would be only possible to think of a nationwide administrative restructuring of the physical airspace.

Traffic

As far as traffic is concerned, the *total number of flights*, the *number of over-flights*, the *number of vertical movements*, the *number of IFR flights*, and the *number of IFR kilometres* are outputs, which strongly depend on the demand for ANS of the AOs and indirectly of the end users.

Delay

As far as delay is concerned, the *total minutes of delay*, the *total minutes of en-route delay*, and the *total number of delayed flights* can be considered as negative outputs, since they are products of the provision of ANS, but the more the worse. Consequently, also according to [16], they are taken as input variables.

Collinearity

The results proposed by the DEA, as well as some statistical methodologies, may loose some of their meaning when collinearity amongst data exists. Then, it may be sensible to *a priori* perform a collinearity test and possibly to eliminate some of the collinear variables.

As far as delays are concerned, the variable *total minutes of delays* presents a very high correlation index with both the *en-route minutes of delays* (0.96) and the *total number of delayed flights*. Therefore, it could be possible not to consider in the analysis the *total minutes of delays*.

The *total revenues* and the *en-route revenues* result correlated with the *number of IFR km* (0.68 and 0.78 respectively) and with the *vertical movements* (0.79 and 0.85 respectively).

The *vertical movements* present a correlation index of 0.71 with the number of ATCOs; this can be explained with the workload that the ATCOs have to sustain. On the contrary, the correlation with the total staff is very low (0.39); this can be explained with the non linearity of capital expenditures with the output, since large sums are required for capacity investments.

Results

It is important to stress how this benchmarking analysis illustrates the potentials of DEA, since not all the data are real but, for most of the variables, are randomly generated, even if following certain criteria. Therefore, any result does not represent the European picture of the activity of ACCs in year 2000, and the comments on the results are academic.

The principal analysis run contemplates sixty-three DMUs, the European ACCs, and takes into account five variables: the total number of ATCOs, the total number of en-route delay minutes, the total number of delayed flights, the total number of IFR km controlled, and the total number of vertical movements. The analysis is input-oriented and assumes variable returns to scale.

Nineteen ACCs out of sixty-three (30%) result efficient. The efficiency scores are distributed along the entire scale 0-100%, till the least score of 16.81%, and 27 units (42%) are concentrated in the interval 30-59%.

Out of the nineteen efficient units, seven are a benchmark for a very low number of units (from zero to two) and follow, therefore, a niche behaviour; seven are a benchmark for a number of units between six and nine; and five are a benchmark for a number of units higher between ten and twenty-four.

Out of the nineteen efficient units, only six present an activity, where the strengths are distributed on two of the three inputs of the analysis, and only one on all the three inputs, i.e., the number of inputs with a positive weight to maximise the outputs-inputs ratio is, respectively, two and three. The remaining twelve units focus their strengths on only one input, and this implies a less stable behaviour. As far as the outputs are concerned, only four units weight both the variables.

As far as the surface controlled by the various ACCs[2] is concerned, twenty-five units (39%) manage a surface inferior to 100,000 km^2. Among the efficient units, only four manage a surface inferior to 100,000 km^2 (6%). This could be a hint, according to which a bigger surface, and therefore a bigger airspace allows for a better exploitation of the fixed resources. In fact, a peculiarity of the air transport industry is the non linearity of capital expenditures with the output (typically large sums are required for capacity investments). Among the units presenting an efficiency score inferior to 50%, the units managing a surface inferior to 100,000 km^2 are ten (52%).

As far as the quality of traffic is concerned, out of the efficient units, six (7%) handle more than 300,000 vertical movements[3]. The same number (and percentage) among the units presenting an efficiency lower than 50%. In this case, the quality of traffic managed, represented here by the number of vertical movements handled, does not discriminate between the efficient or not efficient ACCs. Nevertheless, higher numbers of vertical movements generate bigger workloads for the ATCOs; this is a hint for interpreting the productive efficiency of the ATCOs of the different ACCs.

Some observations can be done about the productive efficiency relative to the staff of the ACCs. In the analyses run, both the *total number of staff* and the *total number of ATCOs* are taken into account. Two differential analyses have been done, where only one variable changes: in the first analysis the *total number of ATCOs* is taken into account, in the second analysis, all else being equal, the *total number of staff.*

When considering the sets of efficient units in the two analyses, it is possible to point out that six units, efficient in the first analysis, are not efficient in the second analysis. The weights attributed by these units to the variable *total number of ATCOs*, is high, ranging between 0.73 and 1. Also the weights attributed by these units to the variable *total number of staff* are high, ranging between 0.78 and 1. Probably this result is due to the fact that, with respect to the other units of the set, these six units have a higher number of total staff than of ATCOs, and the objective of a reduction in total staff number could make these units more efficient. The opposite reasoning can be done for two units, which are not efficient (90.43% and 86.46% respectively) when considering the number of ATCOs, and are efficient when considering the total staff.

[2] The surfaces of the European ACCs, in this example, which comprehends also randomly generated data, vary from a minimum of 20,273 km^2 to a maximum of 3,441,416 km^2.

[3] The number of vertical movements handled by the European ACCs, in this example, which comprehends also randomly generated data, vary from a minimum of 9,328 to a maximum of 981,135 vertical movements.

In [14] it is reported that in Australia, e.g., a rationalization of the number of ACCs has allowed to reduce nationwide the number of total staff (maintaining almost unchanged the number of ATCOs) and to improve the efficiency of the ACCs.

It could also be possible to make some comments on the geographic commonalities of the ACCs. As far as Norway is concerned, its four ACCs present a very similar behaviour, putting the most weight to the input variable *total number of ATCOs* and to the output variable *vertical movements*. Three ACCs are efficient and one ACC presents a high efficiency score (91.19%).

Finally, it is to stress that the analyses run comprehend both the efficiency of the units assessed and the quality of the services offered. As a first result, it is possible to state that the quality of service is not a critical factor for success for any of the units, even for the units presenting very few minutes of en-route delays or a very low number of delayed flights. These two variables are, in fact, weighted only by three of the efficient units.

The point of view of the end users (who appreciate very low delays) does not emerge; it could be possible to run further analyses on specific sectors. It is, by the way, to keep in mind that most of the data used have been randomly generated. Real data could add important information.

Conclusions

The present framework of ATM presents no direct link between the level of service provided to flights (in terms of imposed delay or deviations from the optimal route chosen) and route charges to be paid by carriers. Moreover, the charging system based on a full cost recovery mechanism does not seem to give the necessary signals for ANSPs to supply the optimal amount of capacity at the right time and at the right location.

Hence, the investigation of innovative route charge pricing schemes becomes a necessary task. Economic incentives could be applied to ANSPs to promote status and ways of operation positively affecting the behavior of the system, both from the point of view of ANSPs and of the customers. In such sense, the authors are investigating the applicability of performance based regulation techniques for the ACCs, starting from the analysis of their use in different economic systems (cf. [10]). The present benchmarking of the ACCs by means of DEA is considered in this context. In the paper, the main areas for the ACCs evaluation are outlined and a benchmarking exercise is presented. Even if some of the data are not real but have been randomly generated, the potentials of DEA are outlined.

In the incentive regulation techniques, efficiency improvements are driven by rewarding good performance with respect to some benchmarks. The choice of appropriate benchmarks and techniques to measure performance is therefore a key issue for the regulator. The next tasks of the work will concern the analysis of alternative economic incentive regulation mechanisms already used in other industrial sectors (e.g., telecommunications, water and power sectors) and their application to the air traffic system; then, a comparison with the current cost recovery mechanism of the costs incurred by ACCs to provide en-route services; finally, the evaluation of the results of the incentive regulation techniques considered.

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