**Assessing efficiency in Public Service Obligations in European Air Transport using Data Envelopment Analysis**


## Abstract

In recent years, the use of Public Service Obligations (PSOs) in air transport policy has substantially increased. In remote regions, where air transport services are not profitable, the application of this subsidy program is crucial for the economic and social development of these regions. However, there is a great diversity in the provision of PSO services among different regions in Europe. Therefore, it is essential to assess the performances of the air carriers operating in different PSO routes. The present study uses Data Envelopment Analysis (DEA) to assess the efficiency of PSO routes within the European Union and compares them with the performances of the operating airlines, both when operating under this subsidy program and when operating their regular flights. First, DEA was applied to the annual data of several European airlines, and then applied to the data of their PSO routes, so that a comparison can be made between the performance obtained on regular flights and flights under the PSO regime. The results identify which airlines had the best and worst performances, as well as the routes and respective regions of Europe where the airlines tend to score higher and lower in terms of efficiency. Results suggest that the Nordic European countries and the United Kingdom were the regions where air carriers obtained the lowest results, and thus, this empirical evidence should support the public authorities to consider revisiting their PSO contracts, in order to improve their operation.



**Keywords:** European Air transport, Public Service Obligations, Data Envelopment Analysis, Benchmarking.

## 1. Introduction

Air transport services are a key factor in the transport system in remote regions, allowing a more efficient and sustainable use of human and natural resources. Air transport is also very important for long distance trips and for connecting remote areas to the rest of the world (Bråthen, 2011). Airports are one of the gateways to a country and have a high economic and social importance. Moreover, with the increasing affordability of air travel, small and regional airports are also gaining importance in their countries (ACI Europe, 2004; Graham, 2008; Halpern and Bråthen, 2011). Increasing air routes at a given airport generally results in benefits for the economy of the region in which the airport is located, in the sense that it leads to a potential increase in competitiveness and therefore to the increase in the regions' ability to attract new business activities (Brueckner, 2003; Echevarne, 2008). Over the past few decades, in order to favor the opening of new air routes or to increase its current traffic, different strategies and/or subsidy programs have been adopted by governments around the world (Bråthen and Halpern, 2012). Within the European Union (EU), in order to promote the economic development of remote regions, Public Service Obligations (PSOs) have been implemented. As these policies have a significant impact on national and regional economies, it becomes essential to assess the performance of airlines and airports where these strategies have been applied. This benchmarking exercise can then be used to drive public policies and adapt such strategies to specific contexts.

A Public Service Obligation (PSO) is a general concept that defines an obligation, imposed by legislation or contract, on an organization to provide a service of general interest in a particular country or region. It is required mainly due to market´s failure to provide that service to the public as it might not be profitable (due to lack of demand) without any extra subsidy. There are several public service areas where PSOs may be defined, such as transport, postal services, social services, banking, health, etc.

In European air transport, a PSO is a contract under which a government authority proposes to subsidize an airline to perform a service on certain routes. Again, this is necessary for some regions, where scheduled airline services are not profitable, but for the economic and social development of these regions, transportation must be carried out. Currently, thirteen EU member states (Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Greece, Ireland, Italy, Lithuania, Portugal, Spain, Sweden), two European Economic Area (EEA) countries (Iceland and Norway) and the United Kingdom (UK) have implemented PSOs in air transport, which are spread over more than 170 routes in operation across Europe and more than 40 airlines (European Commission, 2019).

PSOs started to be implemented in the 90s, and its objective was to promote population mobility in remote and peripheral areas. In the last few decades, traffic in domestic markets has increased significantly and, consequently, the number of routes contracted under PSOs has continued to grow intensively (Hromádka, 2017).

These PSOs can be classified into two types (European Regions Airline Association, 2016):

- **Open PSO** (21.5% of total PSO routes): any air carrier can operate the PSO if it complies with their requirements, with no exclusivity and no compensation granted;
- **Restricted PSO** (78.5% of total PSO routes): in case no air carrier is interested in operating the route on which the obligations have been imposed, the concerned State may restrict the access to the route to a single air carrier and compensate its operational losses resulting from the PSO. The selection of the operator must be made by public tender at the Community level: only one air carrier can operate the PSO, and if exclusivity is not sufficient to ensure the financial viability of service, then compensation is awarded.

As described, the vast majority of routes are operated by restricted PSOs, which have stricter rules, such as: i) tender is open to EU or EEA carriers only; ii) selection is made as soon as possible; iii) contract is awarded for four years (five years for outermost regions); iv) bid selection criteria are the adequacy of service offered and the level of compensation and v) compensation level must not exceed the amount required to cover the net costs incurred.

PSOs can be awarded, administered and subsidized by either regional or national governments, directly or through associated agencies. The process starts with an invitation to tender, which is published in the Official Journal of the European Union. Once awarded, the air carrier receives the operation of the route for a period not exceeding four years (up to 5 years in remote regions) (Hromádka, 2017). The tender usually stipulates minimum services and maximum fares that should be met by carrier during the contracted period. There are two tender rounds. The initial tender asks for submissions from air carriers who are able to operate services and meet tender specifications without a subsidy. If no carrier is willing to offer a subsidy-free operation, there is a second tender which invites carriers to bid on the basis of receiving a subsidy. The awarding authority then makes a decision taking into account the level of subvention demanded, levels of service offered and any other relevant considerations (Williams and Pagliari, 2004).

All PSO contracts must respect the conditions and the requirements set out in Articles 16 – 18 of the EU Air Services Regulation 1008/2008 (European Commission, 2008). According to the article 16.1, member states can impose PSO air services between an airport in the Community and an airport serving a peripheral region, which might be considered vital for the economic and social development of that region. Moreover, it specifies that such obligation shall ensure the minimum provision necessary of air services satisfying fixed standards of continuity, regularity, pricing or minimum capacity, which air carriers would not offer if they only had their commercial interest in mind.

Although a PSO can be imposed for a route between two countries, the most common cases of PSO protected routes are links between islands from the same country, or between islands and the mainland, where surface or maritime transportation is difficult or expensive. Moreover, several factors condition the operation of an airline on a PSO route. Minimum service levels, limits on fare and cost of travel are examples of factors that influence the level of subsidy required to operate a route, and which often constitute barriers to entry for some airlines. In most of the tenders, the air carrier is required to meet minimum service levels, such as the minimum seating capacity, timetabling of services or a minimum number of frequencies to be provided during the contract period. Service levels are established based on what the managing authority considers to be the adequate service standards on each route, taking into account traffic volume and sector distance.

A particular challenge faced by PSO administering authorities is to ensure that the bidding processes are sufficiently competitive. The problem for many potential new entrants is that there can be significant sunk costs associated with operating PSO services. This may partly explain why, in some of the most remote and low traffic density PSO markets, long-established local air carriers continue to dominate their national PSO markets (Williams and Pagliari, 2004). It is up to regional or national governments to decide upon which routes should be protected by a PSO regime and have an associated subsidy, and those that do not. However, within the European Union, government bodies appear to have different priorities, notions and preferences regarding that decision. This suggests that there are major inconsistencies in the approach and commitment to the provision of social air services, which leads to a certain degree of diversity in the application of PSOs in the European air transport. Thus, for administering authorities and airlines to be more aware of the decisions taken regarding PSOs in the next years, it is essential to evaluate the performance of the airlines operating PSO routes, taking into account both the restrictions imposed and the required service levels, as well as the results achieved by air carriers.

Outside the EEA, other subsidy programs similar to PSOs have been applied. In the US, since

1978, an air service subsidy system for small communities called the Essential Air Service Program (EAS) has operated, which is administered by the Department of Transport (DoT). Moreover, while in the European PSO system only the carrier that wins the tender can operate, in the US EAS system, a second carrier that is able to offer subsidy-free services can enter the market. In these circumstances, the DoT notices the carrier that had previously won the tender that the subsidy will be withdrawn and the concerned carrier has the choice of continuing to operate without subsidy, or withdraw from the route (Williams and Pagliari, 2004).
In other countries, other subsidy programs are applied. In Australia, for example, the Remote Air Services Subsidy (RASS) scheme is implemented in a different way. While the EAS and PSO tenders out contracts in a competitive bidding system, the RASS subsidizes a regular weekly air transport service for the carriage of passengers and goods, such as shipments of food, medication, mail, educational materials and other urgent supplies to remote and isolated regions of Australia (Australian Department of Infrastructure, Transport, Regional Development and Communications, 2020).

Although the EEA framework is almost identical to the EU framework, the present research will focus solely on the PSO operations in the thirteen EU Member States, plus the UK, in an attempt to ensure a fair comparison between operators governed by similar PSO contracts under the same European policy. In addition to the PSO routes, airlines were also evaluated taking into account their operations outside the PSO regime, to understand whether or not they can achieve similar performances when operating under this subsidy program. Data Envelopment Analysis (DEA) was the benchmarking technique chosen, as it is the most commonly used tool in performance measurement studies in air transport, though sparsely used for airlines (Cavaignac and Petiot, 2017). In fact, DEA has been extensively used to assess the comparative performance of full-service carriers and low-cost carriers (Assaf and Josiassen, 2012, Barbot et al., 2012), and less on the comparison of routes (Coli et al., 2011) and especially PSO routes.

The present paper is structured in seven sections. Section 1 provides an introduction to the PSO in European air transport, highlighting their importance in the airline industry, detailing their operation and comparing it with other subsidy programs outside Europe. Then, section 2 provides a literature review, summarizing previous studies related to airline performance measurement and PSOs in air transport, in order to identify the main research gaps and provide an overview on the main research opportunities on this topic. Section 3 briefly introduces the DEA method. Afterwards, section 4 applies the DEA to the airlines' annual data to assess their performance, indicating the selected airlines and describing the different variables. Three analyses are performed. Similarly, section 5 also applies the DEA to assess the performance of PSO networks, describing the variables used for the PSO routes. Two analyses are performed. Then, section 6 discusses the results obtained in the analyses carried out in the previous sections, while comparing the results obtained by the airlines with those obtained by the PSO routes. Finally, section 7 summarizes the main conclusions, identifies some limitations and questions for further research.

## 2. Background and State of the Art

This second section summarizes the past studies on measuring airline performance and on the application and use of PSOs within the EU. It also summarizes the main studies and identifies the research gaps, while providing an overview of the current research opportunities.

### 2.1. Measuring airline performance

A large number of studies measured the productivity and efficiency of airlines. This subsection provides a review of some of these studies, namely on those where DEA was used.

Merkert and Hensher (2011) conducted a study, using a two-stage DEA approach, to investigate the impact of strategic management and fleet planning decisions on the efficiency of 58 airlines between 2007 and 2009. Besides measuring technical efficiency, which is the most addressed topic in the literature and refers to the optimal use of resources, the authors also focused on allocative efficiency and cost efficiency, most used in economics. While technical efficiency only considers physical indicators, the other efficiencies are addressed when information on input prices is available. Allocative efficiency refers to the optimal mix of the inputs, and cost efficiency is the combination of technical and allocative efficiency and refers to choosing inputs at a given level of service so that the cost of production is minimized. They found that the overall efficiency of the airlines has decreased over the analyzed two years. The results showed that airlines with large aircrafts and only a small number of aircraft families in their fleet had relatively high efficiency scores. In addition, the airline size also had a positive impact on all three types of efficiency. On the other hand, stage length and age of fleet were less relevant. These results suggest that airline management that aims to reduce costs should focus less on stage length and fleet age and more on the other variables, such as airline size, aircraft size and number of different aircraft families in the fleet.

Later, Joo and Fowler (2012) employed DEA to measure and compare the efficiencies of 90 airlines in Asia, Europe and North America, using annual financial and traffic data from 2010. Results indicated that airlines in Europe were less efficient than those in Asia and North America, with no significant differences between these last two regions. The authors also identified that revenues and expenses were significant for explaining the efficiency scores of airlines.

Recently, Kuljanin et al. (2019) analyzed the performance of airlines using DEA, with a particular focus on those operating in Central and South-East Europe. The study involved 17 airlines that operated European airports in 2008 and 2012, during the economic crisis. Although the results revealed that the efficiency scores can vary for different outputs used, the two major European low-cost carriers (LCCs), Ryanair and EasyJet, were undoubtedly the most efficient when compared to the other selected airlines. Concerning the airlines' efficiency, the authors concluded that those in Central Europe tend to be more efficient than those in South-East Europe, but both are less efficient than their counterparts from the rest of Europe. Overall, comparing the years 2008 and 2012, airlines have increased their efficiencies, mainly due to the adoption of new technologies.

Moreover, other studies have evaluated the performance of LCCs and the effects of these airlines on airports' efficiency. Chang and Yu (2011) analyzed the performance of 16 low-cost airlines in Europe, the United States and Asia and identified the inefficient ones, indicating those that should reduce their inputs or increase their outputs in order to become efficient. Barbot et al. (2008) also found that LCCs are usually more efficient than full-service carriers, because of the business model they follow. Pyrialakou et al. (2012) used data from 10 Greek airports that handle approximately 85% of LCC demand in the country to show that LCC traffic had significantly affected the airports' efficiency. On the other hand, Martini et al. (2013) analyzed 33 Italian airports and concluded that LCCs did not affect the efficiency, revealing some inconsistencies between the different studies on the performance of LCCs.

### 2.2. PSOs in Air Transport

A number of studies focused on PSOs in air transport. Merkert and Williams (2013) evaluated the efficiency of 18 European airlines under the PSO regime between 2007 and 2009 by applying a two-stage DEA approach. Their key and most significant finding was that the number of months remaining until the end of the PSO contract has a positive impact on efficiency, i.e. in the early stage of PSO contracts the operators obtain better results than when they are near the end. This points to the lack of incentives to improve the efficiency before the tender finishes as a result of limited competition. The results obtained also show that operators with a greater number of PSO contracts tend to be more efficient than those with few or only one PSO contract. However, determinants such as ownership and duration of PSO contracts had no significant impact on efficiency. Ownership was a dummy variable used to distinguish PSO contracts applied to private operators from the publicly owned ones. Another finding was that the average sector length flown harms the airlines' efficiency.

Abreu et al. (2018) evaluated the effects that two changes in PSO system on Canary Island routes had on the number of passengers transported. In 2006, due to an over 40% increase in demand for air transport, a procompetitive reform was carried out, by offering airlines greater freedom to adjust their offer, establishing a more flexible tariff system and introducing new minimum requirements for frequencies and seats. On the other hand, in 2011, due to a sharp decrease in demand, a restrictive change was performed by limiting the access to a single airline in a restricted period. The authors created their own database on demand factors for the period 2002–2015 and concluded that only the procompetitive reform generated increases in demand. The results of this study point to the need to make market access more flexible to benefit society, generating increases in passenger volume.

Calzada and Fageda (2012) analyzed the effects of price discounts and PSOs applied to Spanish routes during the period 2001–2009, finding that routes that benefit from price discounts, offered by the government to island residents, are those where airlines set higher prices. This occurs because these routes tend to have a higher demand than the rest of the country's domestic routes. Another finding was that airlines that operate inter-island routes on which their services are regulated by price caps and frequency floors charge lower prices and schedule a higher number of frequencies than on unregulated routes. Overall, this study suggests that price discounts for island residents help ensure the profitability of routes regulated by PSOs. Later, Calzada and Fageda (2014) analyzed the effect of universal service policies, such as price discounts and PSOs in the level of competition and the number of flight frequencies of airlines in the period 2002–2010 in the five largest European domestic airline markets (France, Germany, Italy, Spain and UK). The results show that price discounts have increased the competitive level and the number of frequencies. Moreover, the use of PSOs reduced the competitive level and had different effects on the number of frequencies, depending on the regulation of each country (open or restricted routes). The authors concluded that the emergence of low-cost airlines increased the level of competition and the number of frequencies. This happened due to new management strategies and the use of smaller and cheaper aircrafts by LCCs, which make profitable routes that are usually ignored by larger airlines. In fact, some of these management strategies were discussed by Bråthen and Halpern (2012). Based on a literature review and experiences with services under EAS and PSOs, the authors identified some factors that could increase the efficiency of the services and improve the economic benefits for remote regions. It is recommended that factors like the need for subsidies, air fares and PSO bidding process should be used to make the regional air transport system viable to support regional economic development. Santana (2009) also analyzed a set of European and US regional air carriers between 1991 and 2002 to show the extent to which operating under Europe's PSOs or US's EAS affected the costs of the airlines. Results indicated that PSOs have increased the cost of regional airlines in Europe, but not in the US.

Boonekamp et al. (2018) presented a regression model to identify the most important determinants for air travel demand. One of the main results obtained was the positive impact on passenger demand of two innovative variables used: aviation-dependent employment and ethnic links. Ethnicity variable was calculated by the sum of the number of people born in the origin country living in the destination country and vice versa. In addition to these variables, the larger presence of LCCs on a route also showed a positive impact on demand. Results showed that PSO regimes stimulate the passenger traffic.

### 2.3. Research Contribution

Based on studies explored in the previous subsections, Table 1 was built and summarizes the main studies. Firstly, there is a variety of studies that evaluate the performance of airlines. However, studies on the efficiency of airlines operating PSO routes are very limited, and most of them are focused on economic variables, such as subsidies, price discounts or fares and their relationship with management strategies, providing little information about the relative efficiency of the analyzed airlines. Moreover, a large number of these studies only cover a specific region, a country or a small set of countries, with few comparing several countries within Europe.

Having said that, the contribution of the present paper is to assess the relative efficiency of airlines and their PSO routes, with more focus on traffic indicators and less on economic variables. Moreover, it also aims to compare the efficiencies of airlines when operating on PSO routes with their efficiencies when operating their regular routes (i.e. outside of PSO routes). Such a comparison has not been previously conducted and cannot be found in the literature, to the best of our knowledge.

*Table 1 - Summary of the main reviewed studies on airline performance measurement and PSOs in air transport.*

| Reference | Method | Sample data | Input variables | Output variables | Contribution |
|---|---|---|---|---|---|
| Merkert and Hensher (2011) | DEA, Tobit | 58 airlines worldwide (2007 – 2009) | Labour (FTE), Available tonne kilometres (ATK) | RPK, Revenue tonne kilometres (RTK) | Investigate the impact of strategic management and fleet planning decisions on airline efficiency |
| Joo and Fowler (2012) | DEA, Tobit | 90 airlines in Asia, Europe and North America (2010) | Operating expenses | Operating revenues, Passengers, RPK, PLF | Measure and benchmark operating efficiencies of major airlines in Asia, Europe and North America |
| Kuljanin *et al.* (2019) | DEA | 17 European airlines (2008, 2012) | No. of employees, Fleet size, ASK, Cost per ASK, Employee cost per ASK, Delay | Aircraft per employee, Passenger per employee, RPK, PLF, Passengers, Operating revenue, Destinations | Analysis of the performance of major carriers across Europe, with particular focus on those operating in Central and South-East Europe |
| Merkert and Williams (2013) | DEA | 18 European airlines under PSO regime (2007 – 2009) | Labour (FTE), Available seat kilometres (ASK) | RPK, Realised departures (flights) | Compare the efficiency of airlines operating under PSO regime and determine the impact of specific determinants on efficiency |
| Abreu *et al.* (2018) | Regression | 22 Canary Island routes (2002 – 2015) | - | - | Evaluate the effects of two changes in European policy on the number of passengers |
| Calzada and Fageda (2012) | Regression | 86 domestic routes in Spain (2001 – 2009) | - | - | Analyse the effects of price discounts and PSOs in the Spanish airline market |
| Calzada and Fageda (2014) | Regression | Routes in France, Germany, Italy, Spain and UK (2002 – 2010) | - | - | Analyse the effects of price discounts and PSOs in the level of competition and the number of flight frequencies in the airline markets |
| Santana (2009) | Regression | 17 European and US regional airlines (1991 – 2002) | - | - | Analyse the impact of PSOs or EAS in the costs of regional airlines |

Based on the state of the art, a set of variables was selected and are shown in Table 2. These variables will be further clarified in sections 4 and 5.

***Table 2 - Variables under analysis***

| | **Regular routes** | **PSO routes** |
|---|---|---|
| **Inputs** | Available seat kilometres (ASK)<br>Fleet size<br>Full-time equivalents (FTE) | Minimum number of annual seats required<br>Amount of annual compensation<br>Required frequencies |
| **Outputs** | Number of flights[1]<br>Number of passengers<br>Passenger load factor (PLF)<br>Revenue passenger kilometres (RPK) | Actual annual seats offered<br>Number of PSO passengers<br>Passenger load factor (PLF) |

## 3. Methods

This third section briefly introduces the Data Envelopment Analysis (DEA) as a benchmarking technique. Benchmarking is a term used to describe the systematic comparison of the performance of a firm against other firms within the same sector, by comparing their production performance, which transforms the same type of resources (inputs) into the same type of products and services (outputs). These production entities can be firms, organizations, industries, projects, decision making units or individuals (Bogetoft and Otto, 2010). Benchmarking can then be used to support decision making or to control operations, and evaluate various aspects of their processes in relation to the processes of other companies operating in the same environment. Thus, it can identify the most successful companies in their sector, and compares them with their own results and/or processes. This allows organizations to develop plans on how to make improvements or adopt better practices, with the aim of improving their performance.

To conduct benchmarking between different organizations, measuring the efficiency of the concerned firms is a common practice. In a simple way, efficiency can be measured as the ratio between outputs and inputs. Thus, a firm with the highest productivity will be the one with the highest ratio of output per input. The term efficiency, however, is very broad and can be used in various ways and purposes. The efficiency measure most used in the benchmarking literature is the technical efficiency, which was introduced by Farrell (1957) as a measure of productive efficiency. Farrell's idea was to focus on proportional changes, namely the same percentage reduction on all inputs or the same percentage increase on all outputs. In this sense, technical efficiency, also known as Farrell efficiency, considers physical indicators and reflects the ideal

[1] This variable was also used as an input, as it will be further explained later in section 4.

use of inputs in the production process (maximum outputs from a given set of inputs).

Data Envelopment Analysis (DEA) is a non-parametric method to estimate production frontiers and evaluate the relative efficiency of different Decision Making Units (DMUs). DEA calculates a production frontier by applying linear programming, from a sample of DMUs. DEA allows establishing relationships between multiple inputs and outputs. By defining an efficient frontier, the inefficiency of a DMU is determined by measuring its distance to that frontier, indicating its potential for increasing efficiency. On the one hand, the efficiency frontier shows the maximum outputs that can be obtained with different combinations of inputs; on the other hand, it shows the minimum number of inputs necessary to obtain different outputs. DMUs below the frontier are understood as inefficient and DMUs on the frontier are regarded as efficient (Lampe and Hilgers, 2015).

There are other benchmarking methods, such as the Stochastic Frontier Analysis (SFA) or the Total Factor Productivity (TFP). Although DEA is a very popular tool with advantages over the other methods, it also has its shortcomings, and its major drawback is that it does not explain the causes of inefficiency (Lam et al., 2009). Another disadvantage is that it is sensitive to outliers (Boyd et al., 2016), i.e. it is suitable for assessing the performance of a relatively homogeneous set of DMUs or a set of cluster DMUs. Despite these disadvantages, while the other aforementioned methods are more applied in economic research fields, DEA seems to be the preferred method in operational research, with aviation being the sector where it is most applied (Lampe and Hilgers, 2015).

There are two important DEA models: i) the constant return to scale (CRS) model and ii) the variable return to scale (VRS) model.

The most popular DEA model is the CCR model, introduced by Charnes, Cooper and Rhodes (1978). They introduced a ratio definition of efficiency which generalizes the single-output to single-input ratio definition for a single DMU to multiple outputs and inputs. This model adopts a constant return to scale, also called CRS model, by assuming that all observed DMUs are operating at the optimal scale. According to the CCR model, the relative efficiency of any DMU is defined as the maximum ratio of weighted outputs to weighted inputs. The weights are not pre-assigned, but rather found by solving a mathematical optimization problem, with a set of constraints so that the ratio output/input should not exceed 1 for every DMU, i.e. all efficiency measures must be less than or equal to one. All the weights are also positive.

Several extensions of the CCR model have been proposed. According to Banker, Charnes and Cooper (1984), a key limitation of the CRS model is its assumption that all observed DMUs are operating at the optimal scale. In the PSO air transport sector, imperfect competition, budget restrictions or other regulatory constraints in PSO contracts often result in firms operating at an inefficient scale (Merkert and Williams, 2013). The BCC model (Banker, Charnes and Cooper), also known as the Variable Returns to Scale (VRS) model evaluates the efficiency of a DMU compared to DMUs of a similar size. It ensures that an inefficient DMU is only benchmarked against DMUs of a similar size, i.e. the scale effect is taken into account. For this reason, the efficiency obtained for each DMU through the VRS model, is often referred to as pure technical efficiency (PTE). One of the drawbacks of the traditional Farrell approach is that when multiple inputs or multiple outputs are used, it does not consider that some inputs could be reduced or some outputs could be expanded without affecting the need for other inputs or the production of other outputs. In order to consider the reduction of inputs or the expansion of outputs, slack variables are introduced.

Finally, there is another version of DEA models called output-oriented models, which attempts to maximize outputs without requiring more of any of the observed input values. Nevertheless, the present work will use input-oriented models because it is assumed that PSO air transport operators have a much higher influence on the inputs. This happens as the "output volumes are substantially influenced by macro-economic factors and often pre-determined by either long term slot contract interests or through the relevant transport authority" (Merkert and Williams, 2013).

## 4. Application to Airlines

In this fourth section, the DEA models previously described are applied to the airlines' annual data. Subsection 4.1 presents information regarding the airline dataset, namely the selected airlines, the years under analysis and the variables that served as inputs or outputs. In subsection 4.2, three different analyses are performed using different inputs and outputs, and the results of the technical efficiencies (from the CRS and VRS models) of each airline are analyzed.

### 4.1. Airlines Data

This section describes the data used for the analyses. Table 3 shows the 11 selected airlines, and the respective analyzed years. Only European airlines that performed PSO operations were selected, though in this first phase, the data used were the annual results of the entire operation of each airline, between 2013 and 2019.

*Table 3 - Sample of the airlines and years analyzed.*

| Airline/Group | Country | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|
| Croatia Airlines | Croatia | ● | ● | ● | ● | ● | ● | - |
| Ryanair | Republic of Ireland | ● | ● | ● | ● | ● | ● | ● |
| Air France – KLM (Group) | France | ● | ● | ● | ● | ● | ● | ● |
| Lufthansa (Group) | Germany | ● | ● | ● | ● | ● | ● | ● |
| Aegean (Group) | Greece | ● | ● | ● | ● | ● | ● | - |
| Alitalia SAI S.p.A | Italy | - | - | - | ● | ● | ● | - |
| SATA Internacional | Portugal | ● | ● | ● | ● | ● | ● | - |
| SATA Air Açores | Portugal | ● | ● | ● | ● | ● | ● | - |
| Eastern Airways | UK | ● | ● | ● | ● | ● | ● | - |
| Loganair | UK | ● | ● | ● | ● | ● | ● | - |
| Flybe | UK | ● | ● | ● | ● | ● | ● | - |

Note: Symbols determined whether (●) or not (-) that airline and year was included in the sample. The sample is quite balanced, except for the year 2019 and Alitalia group.

All data was collected from the annual reports, available on the websites of each airline. At the time of data collection (March 2020), only three airlines/group of airlines had reports for the year 2019 available: Ryanair, Air France–KLM and Lufthansa. Alitalia only had available reports for the previous three years (between 2016 and 2018). Some of the carriers are presented as a group of airlines, such as Air France–KLM, Lufthansa and Aegean. In these cases, the group includes not only the main airline but also all their subsidiaries, with some being smaller airlines that carry out a small number of operations per year. In such cases, reports include the annual results of the entire group of operators, which might have a substantial influence when compared to the others.

The variables collected are presented in Table 4:

*Table 4 – Variable names and descriptions.*

| Variable name | Description |
|---|---|
| Full-time equivalents (FTE) | Employed staff in the referred period |
| Available seat kilometres (ASK) | A measure of the offered capacity of each operator, calculated as the total number of seats available for the transportation of passengers multiplied by the number of kilometres travelled |
| Number of flights | Flights performed in the analyzed period |
| Fleet size | Number of aircrafts owned by each airline |
| Number of passengers | Passengers served in the analyzed period |
| Passenger load factor (PLF) | Annual occupancy rate of the aircraft and is calculated by dividing RPK by ASK |

All data is available online as supplementary material. Table 5 presents a summary of the main descriptive statistics of these variables, namely the mean, standard deviation (SD), minimum

(Min.) and maximum (Max.) values. It is important to mention that, as expected, the correlations between pairs of variables are positive, though around 70% of them are strongly correlated (r > 0.8), which might pose a certain limitation to the DEA application.

***Table 5 - Descriptive statistics of the variables used in Airlines Analyses***

| | N | Mean | SD | Min. | Max. |
|---|---|---|---|---|---|
| **Input Variables** | | | | | |
| FTE | 54 | 30384.67 | 46536.79 | 592 | 137784 |
| ASK ($10^6$) | 51 | 103140.69 | 128368.86 | 237 | 359567 |
| Fleet | 54 | 228.98 | 255.55 | 6 | 763 |
| **Output Variables** | | | | | |
| RPK ($10^6$) | 51 | 87188.20 | 107894.13 | 155 | 296511 |
| Passengers ($10^3$) | 66 | 37390.14 | 49767.94 | 357 | 145190 |
| PLF (%) | 66 | 74.79 | 10.90 | 51 | 96 |
| Flights | 66 | 299149.58 | 372195.60 | 5597 | 1177315 |

Note that the number of observations (N) differs between variables because some reports did not present data on all these variables. Nevertheless, these were the variables that served as input or output in the different analyses conducted on the performance of airlines.

It is important to mention that there is no systematic approach for the selection of inputs and outputs in DEA, as they are largely dependent on the objectives of the analysis and on data availability (Iyer and Jain, 2019). In this case, the variables selected as inputs were the resources used by the airlines, while the outputs were what they managed to produce. The variable "number of flights" was used in all analyses. It is usually used as an output. However, in the third analysis for the airline performance, it was used as an input, as it will be discussed later in subsection 4.2.3.

## 4.2. Assessing airline performance

Three analyses were conducted using different variables as inputs and outputs, and computing the technical efficiencies and slacks resulting from the CRS and VRS models. The CRS and VRS models were compared to understand the difference caused by the scale effect in the results. However, the VRS model results are the focus, as it ensures that airlines are only benchmarked against others of a similar size; while the CRS model assumes that all are operating at the optimal scale. In this subsection, we only plot the VRS efficiency scores for the third analysis, though the other Figures and Tables can be found in the Appendix A.

### 4.2.1 Airline performance: analysis 1

The first analysis is oriented towards airlines performance and was based on the study by Merkert and Williams (2013), where 18 PSO carriers were analyzed, by taking into account their operating results in the financial years of 2007/08 and 2008/09, with a total of 34 observations.

In terms of data, the authors used two inputs: the FTE and ASK; and two outputs: the number of flights and RPK. In this analysis, the same inputs and outputs were used to evaluate the operation of 6 of the 11 airlines between the years 2013 and 2019, totaling 39 observations. The airlines/groups analyzed were Croatia Airlines, Ryanair, Air France–KLM, Lufthansa, Aegean and Flybe. The remaining ones were not considered at this stage as their reports do not provide information on all variables needed.

The results presented very similar efficiency scores for all airlines. Ryanair, Croatia Airlines and Flybe were those that achieved the best performance, with VRS efficiency scores equal to 1 in most of the years studied meaning that they excel in employing their inputs to produce outputs compared to the other airlines used in the analysis. In Appendix A, Table A.1.3 presents a summary of the descriptive statistics of the efficiencies obtained in those years for each airline, using the CRS and the VRS models. Figure A.1.3 shows a boxplot of the efficiencies obtained in the analyzed years. The groups Air France–KLM, Lufthansa and Aegean are those with the lowest average efficiency scores. Smaller regional airlines that are subsidiaries of the groups here analyzed may have had a negative effect on the efficiency scores. This finding is in line with Merkert and Williams (2013), where most regional airlines, such as Airlinair or Air Corsica (subsidiaries of Air France–KLM) presented low efficiency values when compared to the rest of the sample. Moreover, Aegean airlines seems to have lower efficiencies than others, though the average VRS efficiency scores was greater than 0.9.

Moreover, information on the slack variables is in the Appendix. Non-zero input slacks marked in yellow/orange represent the percentage of inputs that could be reduced in order to achieve the same level of output. Non-zero output slacks marked in green represent the percentage of outputs that could be increased, to improve the efficiency obtained. For instance, Air France–KLM (in 2013) and Aegean (in 2015) operated inefficiently: Air France–KLM in 2013 could have improved its performance by increasing the number of flights by 12% and reducing FTE by 35%, even after having reduced all inputs (FTE and ASK) by 7% (PTE = 0.930); whereas Aegean in 2015 had an efficiency of 0.880 but presented zero slack variables, i.e. it could have reduced the quantity of all inputs by 12% without affecting the quantity of outputs produced. Overall, the slack variables show relatively low values, due to the good efficiencies obtained in this analysis.

#### 4.2.2 Airline performance: analysis 2

The second analysis is oriented to operational efficiency of airlines and was carried out using the inputs: FTE and Fleet size; and the outputs: number of flights and total number of passengers. It was possible to include three more airlines in addition to those used in the previous analysis, namely Alitalia, SATA Internacional and SATA Air Açores. Thus, 54 observations were counted. The low efficiencies obtained by SATA Internacional through the CRS model (not considering the scale effect) and the great improvement in efficiencies recorded by Flybe since 2015 stand out. Regarding the former, these results indicate low flight frequency and/or a low number of passengers carried by SATA Internacional. However, when the scale effect is considered (in the VRS model), the airline obtained good efficiency scores, showing good results when benchmarked against airlines of a similar size. In the case of Flybe, a significant increase was registered in the efficiency score in 2015, both in the CRS and VRS models. In fact, in 2015, the airline has substantially reduced the number of employees and the fleet size, and still managed to carry out a higher number of flights and attract a higher number of passengers than in the previous years.

The results showed lower efficiencies for Air France–KLM, Alitalia and Flybe, with VRS efficiency scores close or equal to 1. In Appendix A, Table A.2.3 presents a summary of the descriptive statistics of the efficiencies obtained in this analysis. Moreover, a boxplot comparing the pure technical efficiencies obtained by each company is shown in Figure A.2.3.

The two airlines belonging to the SATA group achieved high VRS efficiency scores in all years, as they used the smallest amounts of inputs, with a Fleet size between 6 and 8 units and FTE around 600 or 700 each. Croatia Airlines and Aegean also used less inputs compared to others (e.g. Fleet size) with good efficiencies. Ryanair also presented an average efficiency value very close to 1 and it acted as a peer for most airlines. In fact, Ryanair made use of much smaller amounts of Fleet size and FTE, and achieved results close to those of Air France–KLM in terms of number of flights and number of passengers, having managed to attract more passengers since 2015. Lufthansa was the one that used the largest amount of inputs and achieved the largest amount of outputs, reaching the largest number of flights. Regarding slack information, Air France–KLM and Alitalia, with the lowest efficiency scores, could have potentially reduced their FTE by up to 60%. Air France-KLM needed to increase the number of passengers between 19% and 44% depending on the year.

### 4.2.3 Airline performance: analysis 3

Finally, a third analysis is oriented to measure how attractable the airline was to passengers. It was conducted, with only one input (number of flights) and two outputs (number of passengers and PLF). The variable "number of flights" is usually used as an output, but here it was used as an input, since this study aimed to determine which airlines made the best use of their flights, based on the number of passengers and PLF reached. All the 11 airlines were analyzed, totaling 66 observations. The VRS efficiency scores and their evolution are shown in Figure 1.

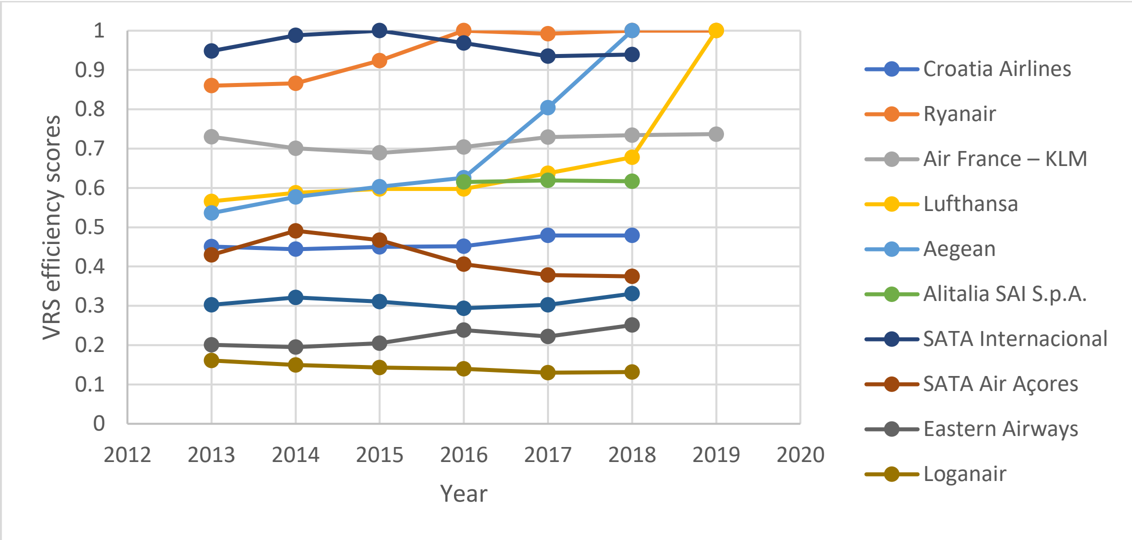


***Figure 1 – Airline Analysis 3: VRS efficiency scores***

The VRS model, which assumes a variable return to scale, shows higher (or at least equal) technical efficiencies than the CRS model, which assumes a constant return to scale. Overall, airlines have been increasing their efficiency over the years, which means that operators are focused on improving their performance year after year.

The descriptive statistics of the efficiencies are shown in Figure 2 (boxplots) and Table 6. Ryanair and SATA Internacional presented the best technical efficiency scores; and the British Airlines Eastern Airways, Loganair and Flybe presented the worst technical efficiencies. Eastern Airways and Loganair registered the lowest occupancy rates (PLF) in the years analyzed, resulting in low efficiency scores. Ryanair registered the highest PLF values, and thus, was one of the airlines with the highest efficiencies.

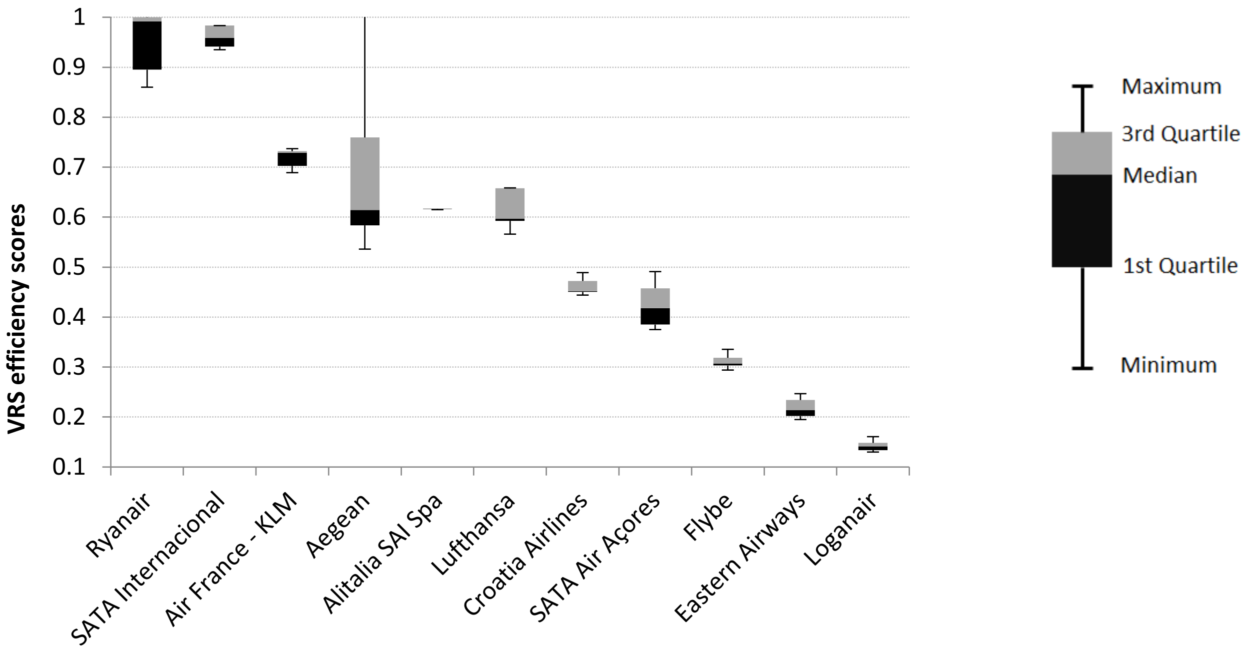


***Figure 2 - Boxplot graph – PTE from Airlines Analysis 3.***

***Table 6 - Airlines Analysis 3: Descriptive statistics of the efficiencies obtained for the CRS and VRS models.***

| | | TE (CRS) | | | | PTE (VRS) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Airline/Group** | **N** | **Mean** | **SD** | **Min.** | **Max.** | **Mean** | **SD** | **Min.** | **Max.** |
| SATA Internacional | 6 | 0.955 | 0.031 | 0.924 | 1.000 | 0.963 | 0.027 | 0.935 | 1.000 |
| Ryanair | 7 | 0.944 | 0.061 | 0.860 | 1.000 | 0.949 | 0.065 | 0.860 | 1.000 |
| Air France – KLM | 7 | 0.711 | 0.019 | 0.689 | 0.737 | 0.717 | 0.019 | 0.689 | 0.737 |
| Aegean | 6 | 0.624 | 0.068 | 0.536 | 0.719 | 0.691 | 0.177 | 0.536 | 1.000 |
| Lufthansa | 7 | 0.621 | 0.047 | 0.565 | 0.685 | 0.666 | 0.152 | 0.566 | 1.000 |
| Alitalia SAI S.p.A. | 3 | 0.617 | 0.002 | 0.615 | 0.618 | 0.617 | 0.002 | 0.615 | 0.619 |
| Croatia Airlines | 6 | 0.453 | 0.017 | 0.437 | 0.475 | 0.459 | 0.016 | 0.444 | 0.479 |
| SATA Air Açores | 6 | 0.356 | 0.030 | 0.308 | 0.397 | 0.425 | 0.047 | 0.375 | 0.491 |
| Flybe | 6 | 0.309 | 0.014 | 0.293 | 0.330 | 0.311 | 0.014 | 0.294 | 0.331 |
| Eastern Airways | 6 | 0.145 | 0.017 | 0.131 | 0.177 | 0.219 | 0.022 | 0.195 | 0.251 |
| Loganair | 6 | 0.126 | 0.004 | 0.121 | 0.131 | 0.143 | 0.012 | 0.130 | 0.161 |

It is interesting to note that SATA Air Açores showed low efficiency scores, contrarily to SATA Internacional, meaning that flights outside the Azores archipelago attracted a greater number of passengers than those carried out internally (between the various islands of Azores). With fewer flights, SATA Internacional was able to reach a higher number of passengers, and consequently higher occupancy rates than SATA Air Açores.

## 5. Application to PSO routes

Having previously explored the airline performance, this fifth section analyses the PSO networks.

Subsection 5.1 presents the input and output variables used in analyses for the PSO routes and subsection 5.2 explores two analyses using different inputs and outputs and the respective efficiencies.

### 5.1. PSOs Data

Here, the data refers to each route, i.e. origin-destination (O/D) pair and only the year 2018 is analyzed, as it is the most recent information available. This data is publicly available on the European Commission website (European Commission, 2019).

The variables used were compiled in table 7:

***Table 7 – Main variables and their description.***

| **Variable name** | **Description** |
|---|---|
| Minimum number of annual seats required by the PSO | It represents the minimum number of seats that must be made available annually by the airline, as imposed by the PSO |
| Actual annual seats offered on the PSO route | The number of annual seats offered by the respective airline on the route in question |
| Amount of annual compensation | It represents the monetary value that is given to each airline to operate the route for which it was designated |
| PSO passengers in 2018 | Number of passengers served by the PSO route in 2018 |
| Required Frequencies | It represents the number of weekly flights imposed by the PSO on each route |
| Passenger load factor (PLF) | It represents the annual occupancy rate on PSO routes |

Table 8 presents a summary of the descriptive statistics of these input and output variables. All data is available online as supplementary material. Data also contains information on the member states that administer each route, the airports involved and the airline(s) operating.

***Table 8 - Descriptive statistics of the variables used in PSOs Analyses***

| | **N** | **Mean** | **SD** | **Min.** | **Max.** |
|---|---|---|---|---|---|
| **Input Variables** | | | | | |
| Minimum number of annual seats required by the PSO | 76 | 121499.38 | 186847.50 | 1860 | 851006 |
| Amount of annual compensation (€) ($10^3$) | 76 | 1801.98 | 2244.42 | 0 | 14100.88 |
| Required Frequencies | 130 | 13.34 | 16.46 | 1 | 95 |
| **Output Variables** | | | | | |
| Actual annual seats offered on the PSO route | 76 | 182679.68 | 291716.52 | 3828 | 1308413 |
| PSO passengers in 2018 | 130 | 92027.68 | 177563.12 | 35 | 948464 |
| PLF | 130 | 0.63 | 0.24 | 0.0206 | 1.0221 |

The variable "Required Frequencies" represents the number of weekly flights imposed by the PSO on each route. In some routes, a range of values is displayed (e.g. 22-28), i.e. on that route the number of weekly frequencies is within that range. In cases where 3 values are presented

(e.g. 3/4/6), each value represents the number of weekly frequencies imposed for a season of the year, according to the expected demand. The highest value corresponds to the summer months (e.g. 6), the lowest to the winter months (e.g. 3), with the remaining value corresponding to the mid-season (e.g. 4). In these cases, the average of these values was used.
Regarding the variable PLF, there are some cases where it has a value greater than 1. This variable is calculated by dividing the number of passengers by the total number of seats available. However, due to the lack of data on the number of seats available on some routes, the PLF was calculated by dividing the number of passengers by the minimum number of annual seats required by the PSO, which in some cases resulted in values greater than 1, and may have an influence on the obtained results.

## 5.2. Assessing PSOs routes performance

Two analyses on PSO routes were performed: i) on assessing the efficiency of the contracts established by the administering authorities with the operating airlines; and ii) on assessing the performance of the airlines on the operated routes. Similarly, only the VRS scores are presented, as it is assumed that, in the PSO air transport sector, most airlines operate at an inefficient scale (Merkert and Williams, 2013).

### 5.2.1 PSOs routes performance: analysis 1

The first analysis on PSO routes used as inputs: i) the minimum number of annual seats required by the PSO and ii) the amount of annual compensation; and as outputs what the airline was able to offer or the results achieved, in this case: i) the annual seats offered on the PSO route and ii) the number of passengers in 2018. It was possible to analyze the performance of 76 routes, where a number was assigned to each route, as indicated in the Appendix B, showing the pure technical efficiencies obtained for each route in Table B.1.
Note that 13 routes achieved maximum efficiency (PTE = 1). Table 9 shows the airports that form these routes, their operating airlines and the member states responsible for administering that route. The most represented airlines were Croatia Airlines and SATA Air Açores, among these 13 most efficient routes. Contrary to what happens on most routes where a monetary value is offered, in the case of SATA Air Açores, the financial compensation is entirely delivered to the airline, which distributes it in the way it seems most appropriate to each of its 14 routes. As there is no public information on the value that SATA Air Açores employs on each route, the total value offered to the airline was divided equally by the 14 routes, which may not correspond to reality. This may have influenced some efficiency results obtained.

*Table 9 - PSOs Analysis 1: PSO routes with maximum pure technical efficiency (PTE=1)*

| Member State | Origin-Destination Airports | | Airlines operating |
|---|---|---|---|
| **Croatia** | Zagreb | Brač | Croatia Airlines |
| **Croatia** | Osijek | Dubrovnik | Croatia Airlines |
| **Croatia** | Osijek | Split | Croatia Airlines |
| **Cyprus** | Larnaca | Brussels | Ryanair |
| **France** | Strasbourg | Amsterdam | Air France |
| **Italy** | Cagliari | Roma – Fiumicino | Alitalia SAI S.p.A. |
| **Portugal** | Ponta Delgada | Flores | SATA Air Açores |
| **Portugal** | Ponta Delgada | Pico | SATA Air Açores |
| **Portugal** | Ponta Delgada | São Jorge | SATA Air Açores |
| **Portugal** | Ponta Delgada | Terceira | SATA Air Açores |
| **Spain** | Palma de Mallorca | Ibiza | Air Nostrum, Air Europa |
| **Spain** | Gran Canaria | Tenerife South | Binter group (Binter, Canarias airlines) |
| **Spain** | Gran Canaria | Tenerife North | Binter group (Binter, Canarias airlines), CanaryFly, Air Europa |

Moreover, three routes in Spain registered efficiency values equal to 1. It is worth mentioning that Spanish routes are open PSO routes, while most of the others are restricted PSO routes. Thus, these three routes were the most efficient among all Spanish open PSO routes. In such cases that an open PSO route achieves maximum efficiency, the need for PSO application might be reconsidered, since these routes are operated by several airlines that do not need financial compensation to operate, i.e. they can obtain profits even without having the exclusivity of the route and without any support from the administering authorities. Moreover, Ryanair only operates a single PSO route and achieved maximum efficiency, where no financial compensation is needed, though the route is exclusive to Ryanair, which probably helped it to achieve this result.

Figure 3 shows the efficiency ranges for each airline that operated at least four PSO routes.

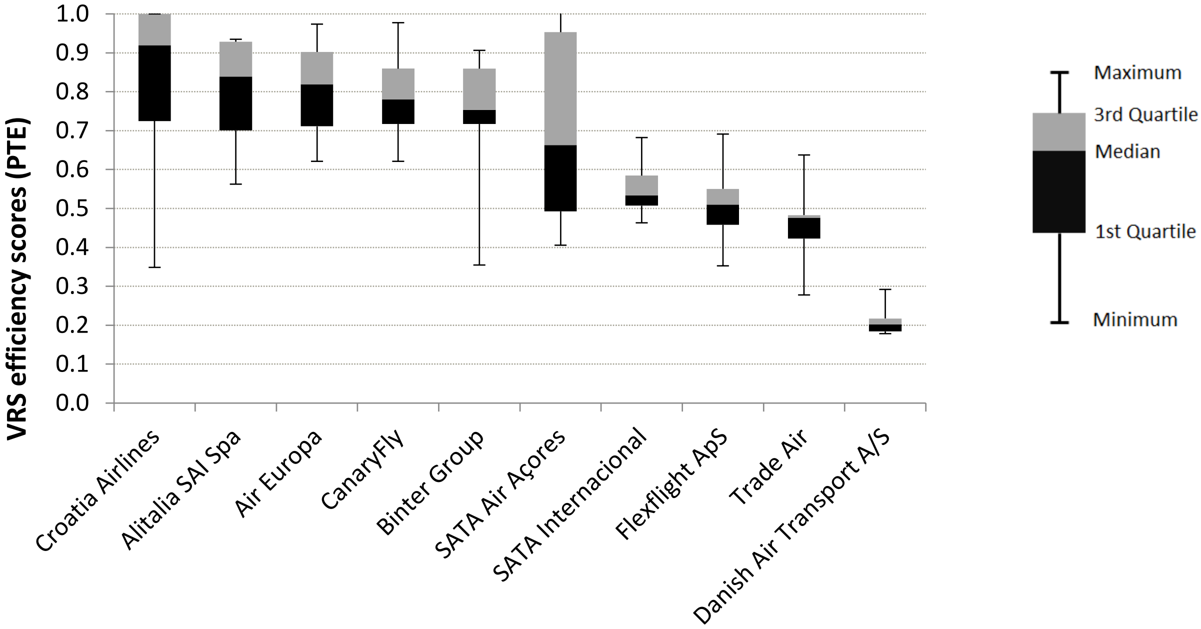


*Figure 3 - Boxplot graph – Airlines PTE from PSOs Analysis 1*

As Figure 3 shows, Trade Air and the Danish airlines (Danish Air Transport and Flexflight) were the airlines with the lowest performance; whereas Croatia Airlines had the best efficiency range (with the third quartile equal to 1). Spanish airlines (Binter Group, Air Europa and CanaryFly) showed very similar efficiency ranges. Besides analyzing how the efficiency is distributed among the different airlines, we also analyzed how they distribute among the member states to understand which regions achieved better results, in order to assess which member states might have established better PSO contracts. Figure 4 shows the PSO efficiencies obtained in the various routes distributed by country. The member states whose routes obtained the worst efficiency scores were Finland, Ireland, Sweden and the UK. Such lower performances may alert their administering authorities to review/negotiate their PSO contracts (e.g. reduce the annual financial compensation, reassess the route frequency requirement among others).

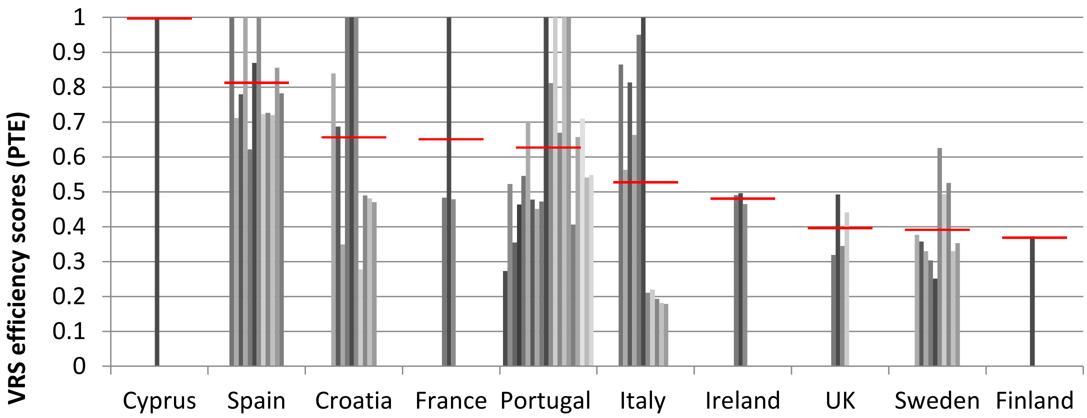

*Figure 4 - Member States PTE from PSOs Analysis 1*

Italy showed the most diverse results. In fact, the most efficient routes were operated by Alitalia, while the most inefficient routes were operated by Danish Air Transport. Apparently, the Danish airline, in 2018, was unable to meet the minimum service levels, having on all routes offered fewer seats than the ones initially required. Thus, this is an example of one of the PSO contracts that should be reviewed.

The information on slack variables is summarized in the Appendix B in Table B.2. Eight routes exhibited significant output slacks, which, given the amount of inputs available, could have increased the percentage of the output number of passengers by more than 100%, namely: Zagreb – Zadar – Pula (Croatia Airlines), Osijek – Zagreb (Trade Air), Osijek – Rijeka (Trade Air), Funchal – Porto Santo (Binter), Lisbon – Santa Maria (SATA Internacional), Corvo – Flores (SATA Air Açores), Sveg – Stockholm/Arlanda (Flexflight) and Pajala – Luleå (Jonair AB). Regarding the input slacks, the highlight is the route Cagliari – Milano and its amount of annual compensation. It is operated by Alitalia, and to become efficient, it should potentially receive 95% less financial compensation from its administering authority. Nevertheless, this is a purely empirical analysis, and the results are obtained taking into account the relative performance of the other routes, but without taking into account further economic, managerial and social aspects factors.

### 5.2.2 PSOs routes performance: analysis 2

This second analysis follows the third analysis in subsection 4.2.3, where the number of flights was used as input, and the number of passengers and PLF were used as outputs, taking into account the annual data of airlines. Thus, this second analysis used the same inputs and outputs, but only with data referring to PSO routes in 2018. A total of 130 routes were covered and the technical efficiencies are shown in Table B.3 in the Appendix B. Table 10 shows the eight routes that reached maximum efficiency (PTE = 1), indicating the origin and destination airports, the operating airlines and the member states responsible for the route administration. All the designated routes link either Origin-Destination pairs that have no road connection or trips (within the same country) in which geographically the road connection is complicated (e.g. within Croatia).

*Table 10 - PSOs Analysis 2: PSO routes with maximum pure technical efficiency (PTE=1)*

| Member State | Origin-Destination Airports | | Airlines operating |
|---|---|---|---|
| **Croatia** | Osijek | Dubrovnik | Croatia Airlines |
| **Croatia** | Osijek | Split | Croatia Airlines |
| **Cyprus** | Larnaca | Brussels | Ryanair |
| **France** | Cayenne (French Guiana) | Saül (French Guiana) | CAIRE |
| **France** | Bastia | Paris (Orly) | Air Corsica – Air France HOP |
| **Greece** | Thessaloniki | Kalamata | Olympic Air |
| **Italy** | Cagliari | Roma - Fiumicino | Alitalia SAI S.p.A. |
| **Portugal** | Funchal | Ponta Delgada | SATA Internacional |

Only one open PSO route achieved maximum efficiency: Bastia – Paris (Orly) route. This is surprising since the open PSO routes are those on which any air carrier can operate as long as it fulfils its requirements, without exclusivity and compensation granted. Moreover, Croatia Airlines included two routes (Osijek – Dubrovnik and Osijek – Split) in the most efficient group. These routes had already achieved maximum pure technical efficiency in analysis 1. The other more efficient routes were operated by Ryanair (Larnaca – Brussels) and operated by Alitalia (Cagliari – Roma – Fiumicino).

Figure 6 plots the efficiency range in a boxplot grouped in operating airline with at least 4 routes. There is a large diversity of the efficiency ranges. The Danish airlines (Danish Air Transport and Flexflight) and the British ones (Loganair and Airtask Group) showed the worst efficiency scores (very close to 0). The Spanish airlines presented similar efficiency ranges, as they operated several PSO routes in common. Croatian airlines presented somewhat different results. While Trade Air showed low efficiencies, Croatia Airlines showed the highest efficiency range, reflecting different patterns between the various routes. Overall, the airlines that showed the best efficiency ranges were Alitalia and SATA Internacional, contrary to what happened with its counterpart SATA Air Açores.

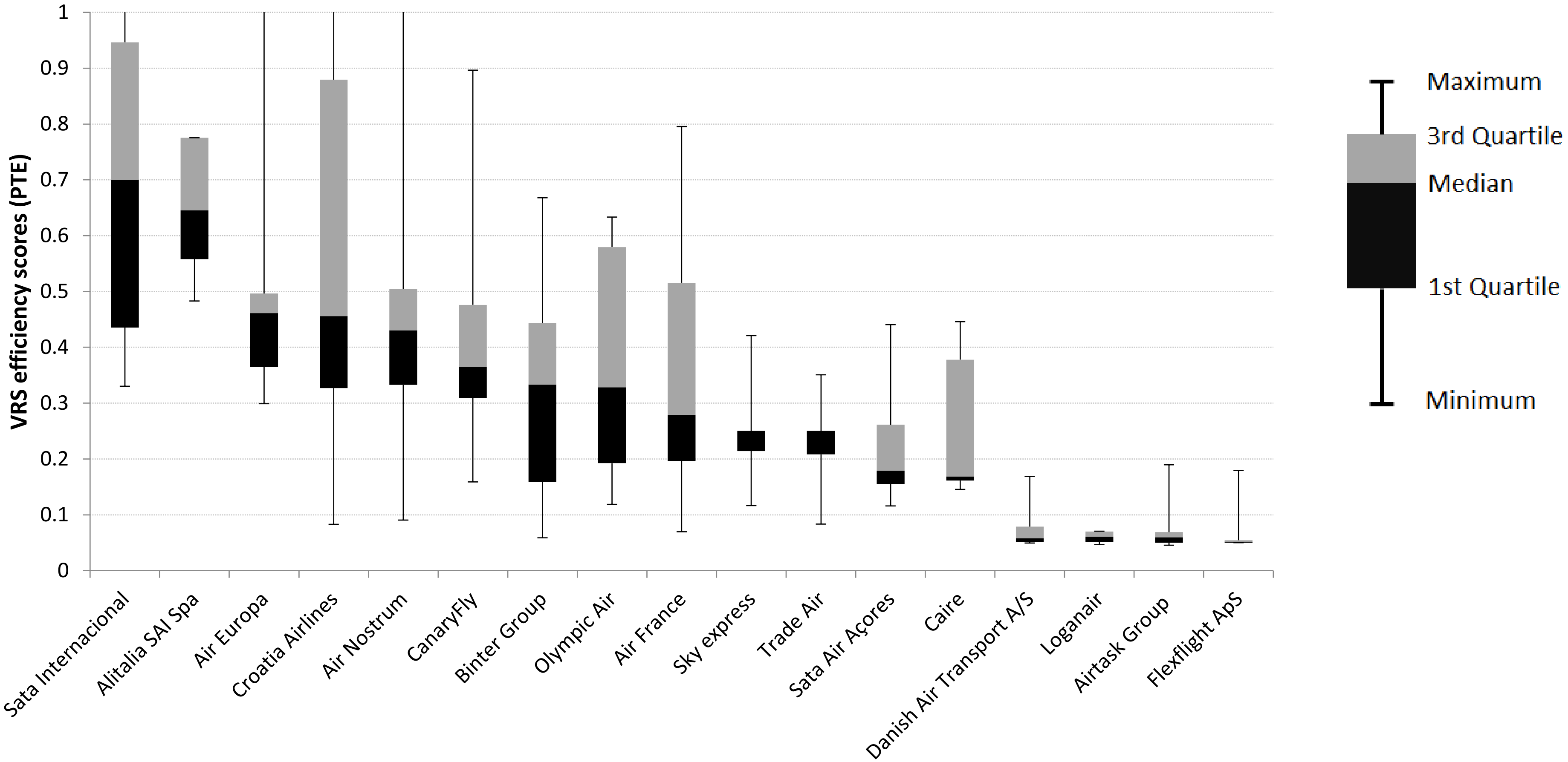


***Figure 5 - Boxplot graph – Airlines PTE from PSOs Analysis 2***

Having presented the PSO route performance grouped by operating airline, Figure 6 presents the associated efficiencies grouped by country.

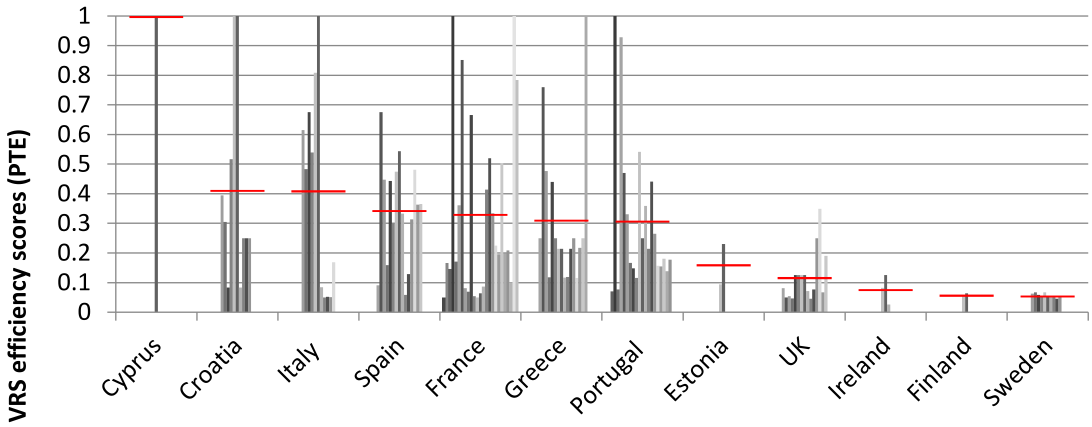


***Figure 6 - Member States PTE from PSOs Analysis 2***

The member states whose PSO routes had the worst efficiencies were Estonia, Finland, Ireland, Sweden and the UK, with the last four also underperforming in analysis 1. This suggests that the Nordic countries and the region of the UK seem to be the regions where contracts should be revisited. In Appendix B, Table B.4 also presents all routes with the worst performances in this analysis. It presents routes that either have a relatively short road connection (up to 4h30), routes that connect small islands to mainland or routes that connect parts of the mainland that are very far away (more than 8h by car).

## 6. Results and Discussion

In this sixth section, a comparison between the main results obtained in sections 4 and 5 is presented, with a summary of all DMUs (airline and/or PSO routes) that achieved maximum efficiency in the different analyses. First, we highlight those that obtained pure technical efficiency equal to 1, as they act as peers for the inefficient ones. Table 11 shows all the peers resulting from the previous analyses. Ryanair is the airline that acts as peer in all analyses, though it only operates one PSO route (Larnaca – Brussels). Croatia Airlines also acts as peer in most analyses, operating three PSO routes.

*Table 11 - Summary of all analyses performed (with input and output variables) and respective peers obtained for the CRS and VRS models.*

| Analysis | Inputs | Outputs | Peers | |
|---|---|---|---|---|
| | | | CRS | VRS |
| Airlines Analysis 1 | - FTE,<br>- ASK | - Flights,<br>- RPK | Ryanair, 2015, 2017, 2018<br>Flybe, 2015, 2016, 2017, 2018 | Croatia Airlines, 2013, 2014, 2015, 2017<br>Ryanair, 2014, 2015, 2017, 2018, 2019<br>Air France – KLM, 2019<br>Lufthansa, 2013, 2017, 2018, 2019<br>Flybe, 2014, 2015, 2016, 2017, 2018 |
| Airlines Analysis 2 | - FTE,<br>- Fleet size | - Flights,<br>- Passengers | Croatia Airlines, 2018<br>Ryanair, 2015, 2016, 2017<br>SATA Air Açores, 2018<br>Flybe, 2016, 2017 | Croatia Airlines, 2017, 2018<br>Ryanair, 2014, 2015, 2016, 2017, 2018, 2019<br>Lufthansa, 2013, 2015, 2016, 2019<br>SATA Internacional, 2015, 2018<br>SATA Air Açores, 2013, 2014, 2015, 2016, 2017, 2018<br>Flybe, 2016, 2017 |
| Airlines Analysis 3 | - Fights | - Passengers,<br>- PLF | Ryanair, 2019<br>SATA Internacional, 2015 | Ryanair, 2016, 2018, 2019<br>Lufthansa, 2019<br>Aegean, 2018<br>SATA Internacional, 2015 |
| PSOs Analysis 1 | - Minimum number of annual seats required by the PSO,<br>- Amount of annual compensation | - Annual seats offered on the PSO route,<br>- PSO passengers | | Zagreb – Brač, **Croatia Airlines**<br>Osijek – Dubrovnik, **Croatia Airlines**<br>Osijek – Split, **Croatia Airlines**<br>Larnaca – Brussels, **Ryanair**<br>Strasbourg – Amsterdam, **Air France**<br>Cagliari – Roma – Fiumicino, **Alitalia SAI S.p.A.**<br>Ponta Delgada – Flores, **SATA Air Açores**<br>Ponta Delgada – Pico, **SATA Air Açores**<br>Ponta Delgada – São Jorge, **SATA Air Açores**<br>Ponta Delgada – Terceira, **SATA Air Açores**<br>Palma de Mallorca – Ibiza, **Air Nostrum, Air Europa**<br>Gran Canaria – Tenerife South, **Binter Group**<br>Gran Canaria – Tenerife South, **Binter Group, CanaryFly, Air Europa** |
| PSOs Analysis 2 | - Frequencies | - PSO Passengers,<br>- PLF | | Osijek – Dubrovnik, **Croatia Airlines**<br>Osijek – Split, **Croatia Airlines**<br>Larnaca – Brussels, **Ryanair**<br>Cayenne – Saül, **CAIRE**<br>Bastia – Paris (Orly), **Air Corsica, Air France HOP**<br>Thessaloniki – Kalamata, **Olympic Air**<br>Cagliari – Roma – Fiumicino, **Alitalia SAI S.p.A.**<br>Funchal – Ponta Delgada, **SATA Internacional** |

By comparing the airline performance in subsection 4.2.3 with the PSOs route performance in subsection 5.2.2, where the same inputs (number of flights) and the same outputs (number of passengers and PLF) were used, Figure 7 plots the PTE for each airline against their mean PTE for the PSO routes operated by that airline. It shows that airline performance is positively correlated with PSO route performance ($r = +0.828, p = 0.003$), i.e. airlines that tend to perform better in their networks also perform better when providing PSO routes.

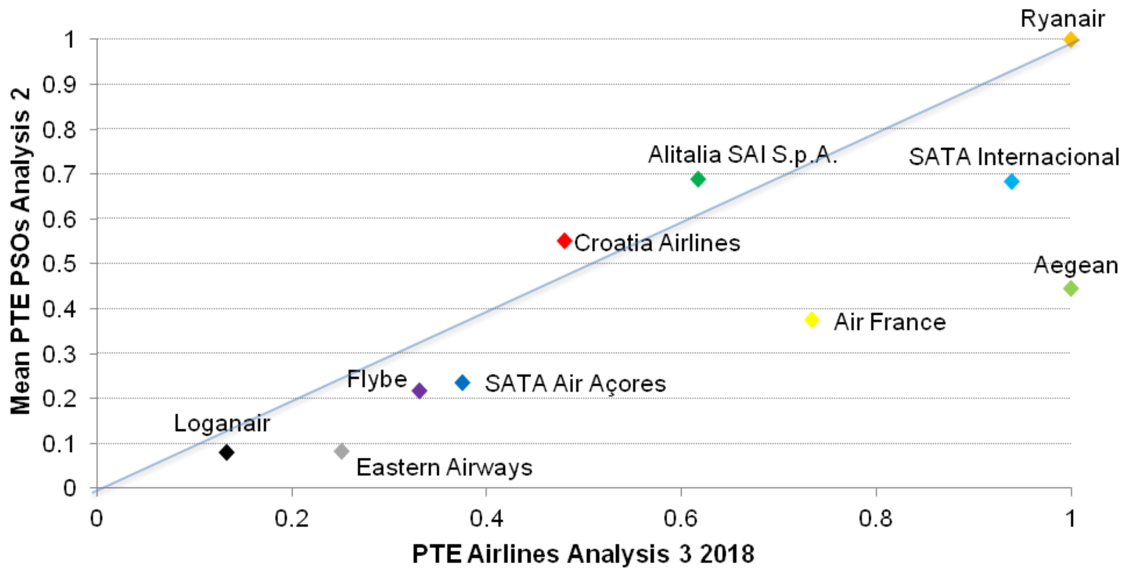


*Figure 7 – Comparison of PTE in Airline performance (analysis 3) with PTE in PSOs route performance (analysis 2).*

Ryanair is a peer in both analysis. Alitalia and SATA Internacional showed high performances in PSO routes. On the other hand, SATA Air Açores presented low efficiency scores in its PSO routes. Croatia Airlines obtained similar average efficiency scores, both for PSO flights and other flights. Air France and Aegean achieved good efficiencies in airline performance (analysis 3), though they scored lower efficiencies in PSOs route performance (analysis 2). In fact, Air Corsica and Air France HOP (subsidiaries of Air France) and Olympic Air (the only subsidiary of Aegean that operates PSO routes) managed to obtain maximum efficiency on a PSO route, though in most of the other routes they achieved low efficiency values, which led to an overall low average efficiency value. Finally, a poor performance of the British airlines (Eastern Airways, Loganair and Flybe) was observed, since all of them presented low efficiency scores, revealing a weak capacity to compete with the others regarding the number of passengers they managed to attract, either on their regular flights or on those operated under PSO. Overall, Figure 7 provides some evidence that airlines tend to obtain similar or lower efficiencies on the PSO routes than on their regular flights.

## 7. Conclusions and Further Research

The air transport sector has been a highly competitive and changing environment with a direct impact on countries' economies. Airlines and air transport authorities are constantly looking for appropriate methodologies to assess their performance and to support their decision-making processes regarding air transport policy and public service obligations. With a great diversity in the application and efficiency of PSOs in the European air transport sector, there is a need to assess the efficiency of PSO authorities and operators, so that the administering authorities can identify best practices in PSO contracts.

The present study used DEA to evaluate the performance of European airlines, both when operating their regular flights and when operating PSO routes. First, DEA models were applied to the annual data of each selected airline, during the period 2013–2019. Then, most European PSO routes were analyzed to assess their efficiencies and compare their operation with performances obtained outside the PSO context. The results provided insights on the efficiency of these operators and indicated that the joint analysis of subsidized and non-subsidized routes might contribute to the characterization of route efficiency, an approach that has not been seen in previous studies.

One of the most relevant findings was the excellent performance obtained by Ryanair in all the analyses, acting as a peer in the analyses on regular flights and on PSO routes. Although there have been some inconsistencies in studies where the efficiencies of LCCs are compared with other airlines (Barbot et al., 2008; Chang and Yu, 2011; Pyrialakou et al., 2012; Martini et al., 2013), Ryanair, as the only LCC used in the sample, strengthened the past findings that these carriers obtain better performances than the other operators (Barbot et al., 2008; Pyrialakou et al., 2012).

Another finding regarded an internal comparison between airlines in the SATA group, where a poor performance was obtained by SATA Air Açores when compared to its counterpart SATA Internacional. This showed that SATA Internacional, with a lower number of flights, managed to obtain a much larger number of passengers than SATA Air Açores, both on routes operated under the PSO regime and on the others. This conclusion was only possible because SATA makes the annual reports publicly available for each of its subsidiary airlines, something that does not happen, for example, for other groups analyzed in this work, such as Air France–KLM, Lufthansa and Aegean.

The results obtained can also improve the way administering authorities currently deal with PSO management. The analysis of the routes that were attributed low performance levels were characterized by either short distances (up to 4h road trips) or very long distanced (at least 8h road trips), which connected geographically edging points of the same country and either the origin or destination was an island with no road connection. On the other hand, high performance levels were attributed to routes that had either no road connection, had a long ferry connection or connected highly populated islands to the mainland. Hence, the routes with the worst efficiencies should be revisited by the administering authorities, and check whether they might be able to renegotiate the amount of annual compensation or the number of seats required.

Overall, the results showed that, among the airlines that operate a larger number of PSO routes, those that obtained the worst efficiency scores were: i) Trade Air, whose routes are administered by Croatia; ii) Danish Air Transport, which operates on routes administered by Finland and by Italy; iii) Flexflight, whose routes are administered by Sweden; and iv) the British air carriers Loganair and Airtask Group, whose routes are administered by the UK. In fact, the results suggest that the Nordic countries and the UK region were the ones with the lowest efficiencies in PSO route performance. On the other hand, the routes that achieved the best performance were: i) Osijek – Dubrovnik and Osijek – Split, operated by Croatia Airlines and administered by Croatia; ii) Larnaca – Brussels, operated by Ryanair and administered by Cyprus; and iii) Cagliari – Roma – Fiumicino, operated by Alitalia and administered by Italy.

Although air PSO policies have been extensively discussed in previous works (Fageda et al., 2018) and routes have been analyzed in an aggregated approach from the perspective of airlines (Merkert and Henscher, 2013), the perspective of a country (Calzada and Fageda, 2014) and the perspective of island connections (Fageda et al., 2018), up to date the efficiency of the routes has not been addressed and discussed in a comparative disaggregated perspective.

It is worth mentioning that the efficiency scores obtained for each group revealed nothing about the individual operation of each of its subsidiaries, and it was not possible to assess, within the same group, which airlines obtained the best and worst performances. In order to strengthen this assessment, the annual reports should be made available for each of the subsidiaries, or within the same report, by distinguishing the annual results obtained by each of them.

For future work, our approach should be applied to the years following those that were analyzed, i.e. from 2019 onwards, with a particular interest on assessing the performances in 2020, as an atypical year that, due to the pandemic situation, has forced air carriers to reduce their operations. In this scenario, it would be interesting to assess which airlines have performed better, and consequently better adapted to adversity, while complying with their public service obligations. Moreover, other subsidy programs around the world, such as EAS and RASS, should also benefit from this benchmarking exercise. Thus, an assessment of the performance of airlines operating under these regimes, and a subsequent comparison between these subsidy programs might be useful to identify differences between the contracts in the various subsidy programs. Finally, though the CRS and VRS models are the most used in DEA applications, there are other models that have potential to be explored, such as the multiplicative models, which provide a log-linear envelopment (Charnes et al., 1994), or the additive model, which combines the input and output orientations in a single model (Cooper et al. , 2002).

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## Appendix A – Airline performance analysis

### Analysis 1: CRS efficiency scores

**Inputs:** FTE (Full-time equivalents), ASK (Available seat kilometers);
**Outputs:** Number of flights, RPK (Revenue passenger kilometers).

***Table A.1.1 - Airlines Analysis 1: CRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 0.805 | 0.811 | 0.814 | 0.816 | 0.856 | 0.846 | - |
| Ryanair | 0.946 | 0.995 | 1.000 | 0.998 | 1.000 | 1.000 | 0.996 |
| Air France – KLM | 0.877 | 0.886 | 0.891 | 0.894 | 0.909 | 0.915 | 0.921 |
| Lufthansa | 0.838 | 0.839 | 0.842 | 0.828 | 0.847 | 0.853 | 0.863 |
| Aegean | 0.863 | 0.863 | 0.839 | 0.841 | 0.894 | 0.898 | - |
| Flybe | 0.954 | 0.994 | 1.000 | 1.000 | 1.000 | 1.000 | - |

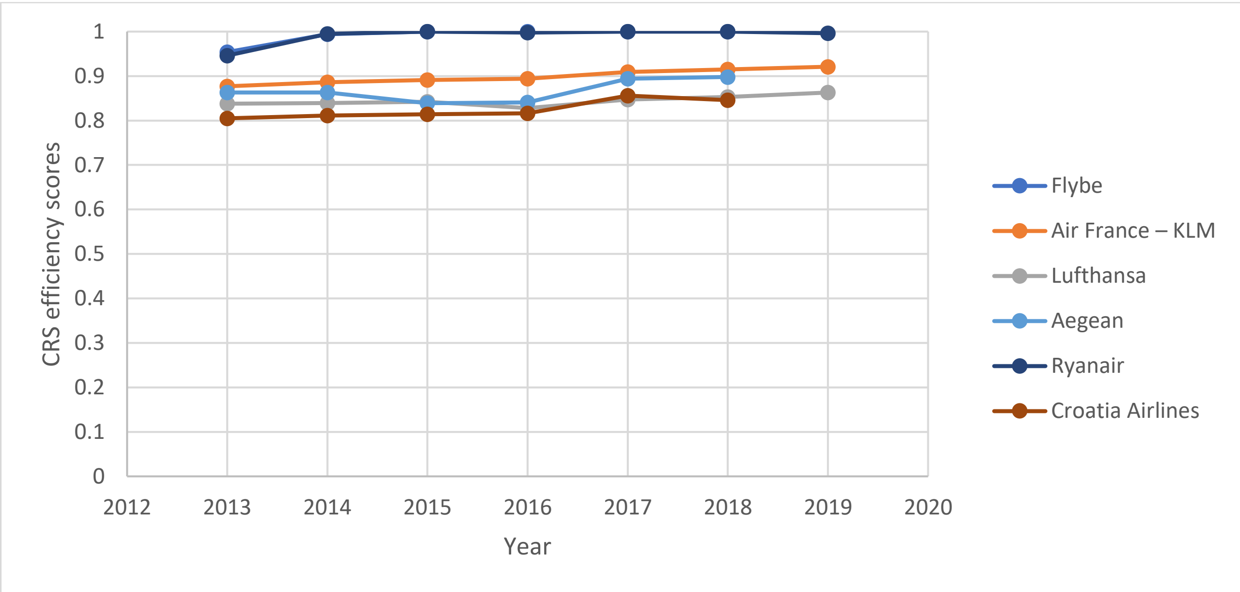


***Figure A.1.1 – Airline Analysis 1: CRS efficiency scores***

## Analysis 1: VRS efficiency scores

**Inputs:** FTE (Full-time equivalents), ASK (Available seat kilometers);
**Outputs:** Number of flights, RPK (Revenue passenger kilometers).

***Table A.1.2 - Airlines Analysis 1: VRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 1.000 | 1.000 | 1.000 | 0.984 | 1.000 | 0.984 | - |
| Ryanair | 0.985 | 1.000 | 1.000 | 0.998 | 1.000 | 1.000 | 1.000 |
| Air France – KLM | 0.930 | 0.941 | 0.950 | 0.957 | 0.982 | 0.996 | 1.000 |
| Lufthansa | 1.000 | 0.972 | 0.968 | 0.955 | 1.000 | 1.000 | 1.000 |
| Aegean | 0.930 | 0.936 | 0.880 | 0.902 | 0.907 | 0.911 | - |
| Flybe | 0.957 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | - |

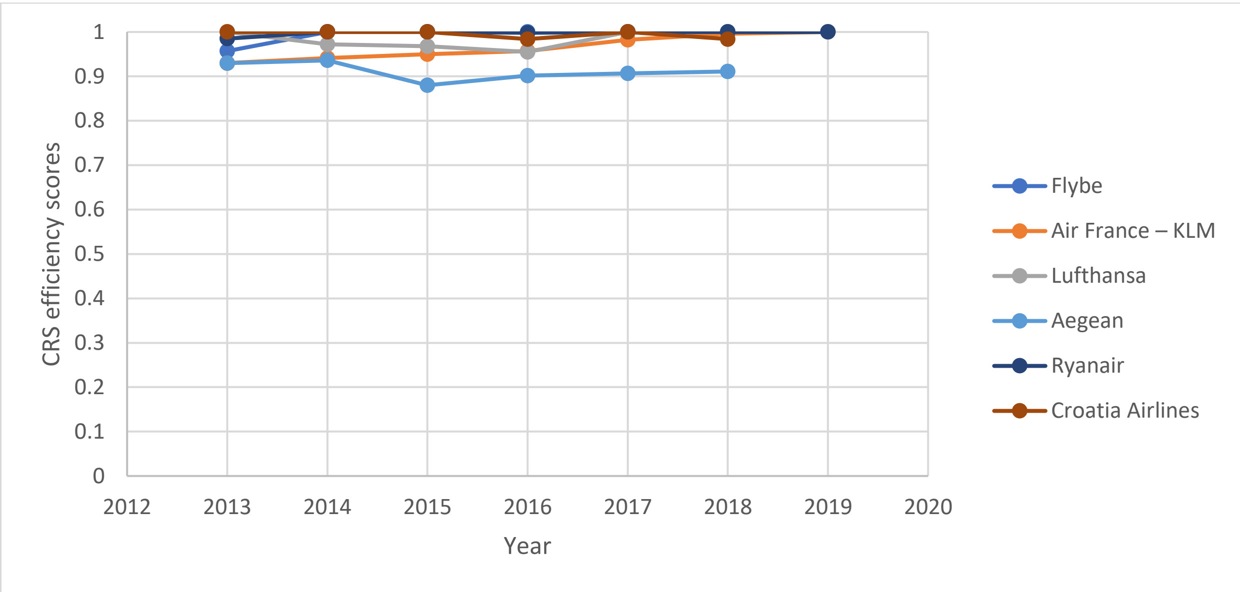


***Figure A.1.2 – Airline Analysis 1: VRS efficiency scores***

*Table A.1.3 - Airlines Analysis 1: Descriptive statistics of the technical efficiencies obtained*

| | | TE (CRS) | | | | PTE (VRS) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Airline/Group** | **N** | **Mean** | **SD** | **Min.** | **Max.** | **Mean** | **SD** | **Min.** | **Max.** |
| Flybe | 6 | 0.991 | 0.018 | 0.954 | 1.000 | 0.993 | 0.018 | 0.957 | 1.000 |
| Ryanair | 7 | 0.991 | 0.020 | 0.946 | 1.000 | 0.998 | 0.006 | 0.985 | 1.000 |
| Croatia Airlines | 6 | 0.825 | 0.021 | 0.805 | 0.856 | 0.995 | 0.008 | 0.984 | 1.000 |
| Lufthansa | 7 | 0.844 | 0.011 | 0.828 | 0.863 | 0.985 | 0.019 | 0.955 | 1.000 |
| Air France – KLM | 7 | 0.899 | 0.016 | 0.877 | 0.921 | 0.965 | 0.028 | 0.930 | 1.000 |
| Aegean | 6 | 0.866 | 0.025 | 0.839 | 0.898 | 0.911 | 0.020 | 0.880 | 0.936 |

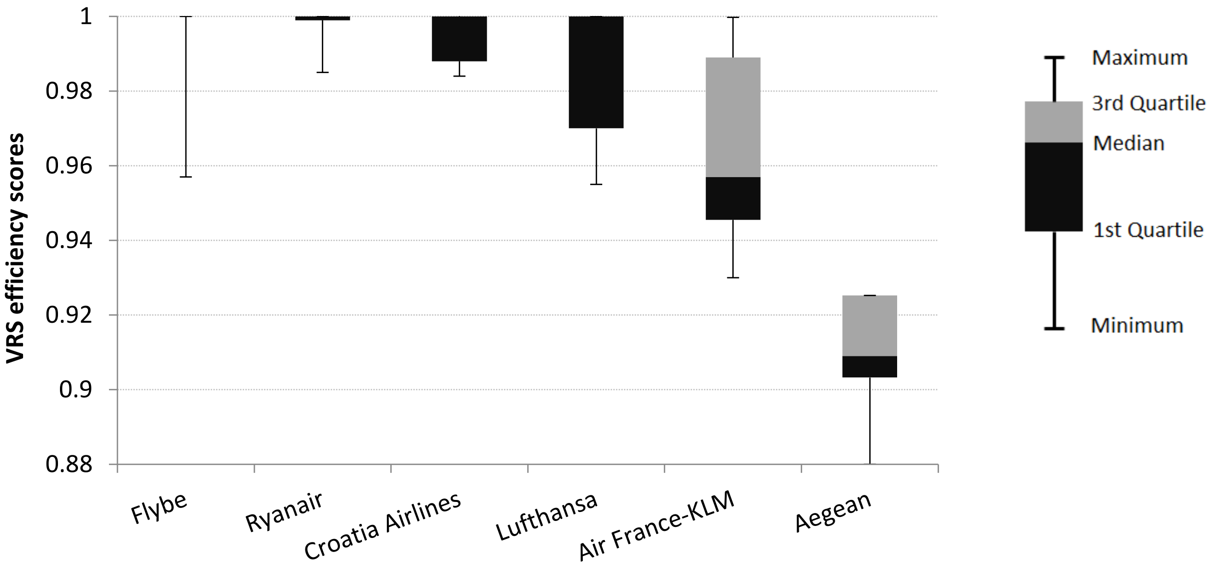


***Figure A.1.3 - Boxplot graph – PTE from Airlines Analysis 1***

*Table A.1.4 - Slack variables and improvement potential (Airlines Analysis 1)*

| | PTE (VRS) | FTE | ASK | Flights | RPK |
|---|---|---|---|---|---|
| Croatia Airlines 2013 | 1 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2014 | 1 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2015 | 1 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2016 | 0.984 | 1% | 0% | 0% | 0% |
| Croatia Airlines 2017 | 1 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2018 | 0.984 | 1% | 0% | 0% | 0% |
| Ryanair 2013 | 0.985 | 0% | 0% | 0% | 7% |
| Ryanair 2014 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2015 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2016 | 0.998 | 0% | 0% | 0% | 0% |
| Ryanair 2017 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2018 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2019 | 1 | 0% | 0% | 0% | 0% |
| Air France - KLM 2013 | 0.930 | 35% | 0% | 12% | 0% |
| Air France - KLM 2014 | 0.941 | 34% | 0% | 6% | 0% |
| Air France - KLM 2015 | 0.950 | 21% | 0% | 0% | 0% |
| Air France - KLM 2016 | 0.957 | 17% | 0% | 0% | 0% |
| Air France - KLM 2017 | 0.982 | 7% | 0% | 0% | 0% |
| Air France - KLM 2018 | 0.996 | 1% | 0% | 0% | 0% |
| Air France - KLM 2019 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2013 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2014 | 0.972 | 13% | 0% | 0% | 0% |
| Lufthansa 2015 | 0.968 | 15% | 0% | 0% | 0% |
| Lufthansa 2016 | 0.955 | 12% | 0% | 0% | 0% |
| Lufthansa 2017 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2018 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2019 | 1 | 0% | 0% | 0% | 0% |
| Aegean 2013 | 0.930 | 0% | 0% | 0% | 0% |
| Aegean 2014 | 0.936 | 0% | 0% | 0% | 0% |
| Aegean 2015 | 0.880 | 0% | 0% | 0% | 0% |
| Aegean 2016 | 0.902 | 0% | 0% | 0% | 0% |
| Aegean 2017 | 0.907 | 1% | 0% | 0% | 0% |
| Aegean 2018 | 0.911 | 7% | 0% | 0% | 0% |
| Flybe 2013 | 0.957 | 31% | 0% | 0% | 2% |
| Flybe 2014 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2015 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2016 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2017 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2018 | 1 | 0% | 0% | 0% | 0% |

## Analysis 2: CRS efficiency scores

**Inputs:** FTE (Full-time equivalents), Fleet size;

**Outputs:** Number of flights, Number of passengers.

***Table A.2.1 - Airlines Analysis 2: CRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 0.889 | 0.927 | 0.927 | 0.959 | 0.987 | 1.000 | - |
| Ryanair | 0.948 | 0.987 | 1.000 | 1.000 | 1.000 | 0.957 | 0.997 |
| Air France – KLM | 0.596 | 0.627 | 0.667 | 0.684 | 0.702 | 0.718 | 0.724 |
| Lufthansa | 0.762 | 0.760 | 0.784 | 0.776 | 0.742 | 0.745 | 0.757 |
| Aegean | 0.994 | 0.970 | 0.927 | 0.905 | 0.942 | 0.909 | - |
| Alitalia SAI S.p.A. | - | - | - | 0.824 | 0.775 | 0.782 | - |
| SATA Internacional | 0.384 | 0.372 | 0.473 | 0.459 | 0.463 | 0.422 | - |
| SATA Air Açores | 0.889 | 0.776 | 0.819 | 0.932 | 0.998 | 1.000 | - |
| Flybe | 0.639 | 0.674 | 0.985 | 1.000 | 1.000 | 0.938 | - |

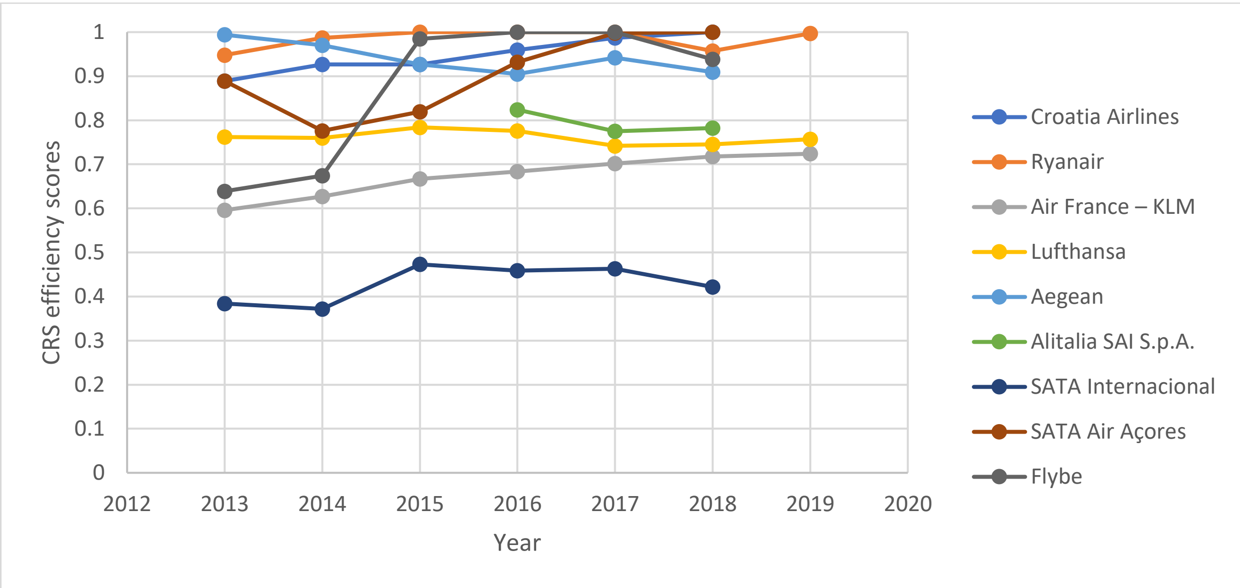


***Figure A.2.1 – Airline Analysis 2: CRS efficiency scores***

## Analysis 2: VRS efficiency scores

**Inputs:** FTE (Full-time equivalents), Fleet size;

**Outputs:** Number of flights, Number of passengers.

***Table A.2.2 - Airlines Analysis 2: VRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 0.892 | 0.955 | 0.960 | 0.967 | 1.000 | 1.000 | - |
| Ryanair | 0.960 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Air France – KLM | 0.672 | 0.722 | 0.775 | 0.791 | 0.804 | 0.822 | 0.830 |
| Lufthansa | 1.000 | 0.975 | 1.000 | 1.000 | 0.989 | 0.994 | 1.000 |
| Aegean | 0.999 | 0.971 | 0.930 | 0.911 | 0.948 | 0.917 | - |
| Alitalia SAI S.p.A. | - | - | - | 0.876 | 0.822 | 0.830 | - |
| SATA Internacional | 0.936 | 0.927 | 1.000 | 0.962 | 0.972 | 1.000 | - |
| SATA Air Açores | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | - |
| Flybe | 0.642 | 0.720 | 0.996 | 1.000 | 1.000 | 0.955 | - |

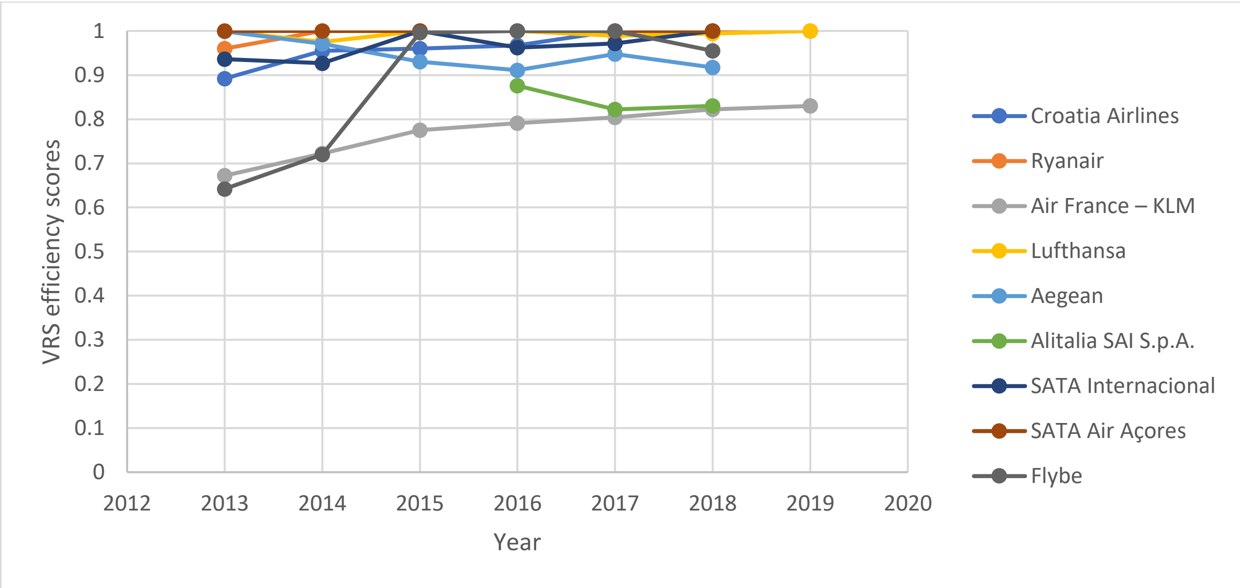


***Figure A.2.2 – Airline Analysis 2: VRS efficiency scores***

*Table A.2.3 - Airlines Analysis 2: Descriptive statistics of the technical efficiencies obtained*

| | | TE (CRS) | | | | PTE (VRS) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Airline/Group** | **N** | **Mean** | **SD** | **Min.** | **Max.** | **Mean** | **SD** | **Min.** | **Max.** |
| SATA Air Açores | 6 | 0.902 | 0.092 | 0.776 | 1.000 | 1.000 | 0.000 | 1.000 | 1.000 |
| Ryanair | 7 | 0.984 | 0.022 | 0.948 | 1.000 | 0.994 | 0.015 | 0.960 | 1.000 |
| Lufthansa | 7 | 0.761 | 0.015 | 0.742 | 0.784 | 0.994 | 0.009 | 0.975 | 1.000 |
| Flybe | 6 | 0.873 | 0.169 | 0.639 | 1.000 | 0.886 | 0.161 | 0.642 | 1.000 |
| Croatia Airlines | 6 | 0.948 | 0.042 | 0.889 | 1.000 | 0.962 | 0.040 | 0.892 | 1.000 |
| SATA Internacional | 6 | 0.429 | 0.043 | 0.372 | 0.473 | 0.966 | 0.031 | 0.927 | 1.000 |
| Aegean | 6 | 0.941 | 0.035 | 0.905 | 0.994 | 0.946 | 0.034 | 0.911 | 0.999 |
| Alitalia SAI S.p.A. | 3 | 0.794 | 0.027 | 0.775 | 0.824 | 0.843 | 0.029 | 0.822 | 0.876 |
| Air France – KLM | 7 | 0.674 | 0.047 | 0.596 | 0.718 | 0.774 | 0.057 | 0.672 | 0.830 |

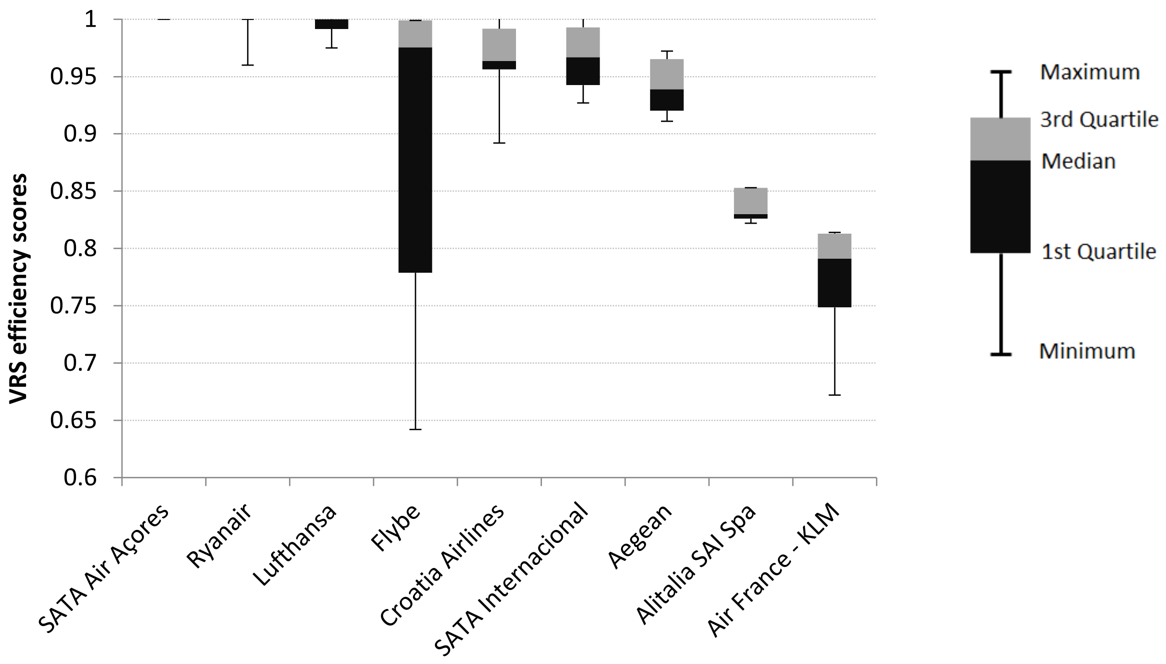


***Figure A.2.3 - Boxplot graph – PTE from Airlines Analysis 2***

*Table A.2.4 - Slack variables and improvement potential (Airlines Analysis 2)*

| | PTE (VRS) | FTE | Fleet | Flights | Passengers |
|---|---|---|---|---|---|
| Croatia Airlines 2013 | 0.892 | 2% | 0% | 0% | 0% |
| Croatia Airlines 2014 | 0.955 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2015 | 0.960 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2016 | 0.967 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2017 | 1 | 0% | 0% | 0% | 0% |
| Croatia Airlines 2018 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2013 | 0.960 | 0% | 1% | 0% | 0% |
| Ryanair 2014 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2015 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2016 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2017 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2018 | 1 | 0% | 0% | 0% | 0% |
| Ryanair 2019 | 1 | 0% | 0% | 0% | 0% |
| Air France - KLM 2013 | 0.672 | 54% | 0% | 0% | 34% |
| Air France - KLM 2014 | 0.722 | 57% | 0% | 0% | 41% |
| Air France - KLM 2015 | 0.775 | 60% | 0% | 0% | 44% |
| Air France - KLM 2016 | 0.791 | 60% | 0% | 0% | 41% |
| Air France - KLM 2017 | 0.804 | 61% | 0% | 0% | 37% |
| Air France - KLM 2018 | 0.822 | 62% | 0% | 0% | 36% |
| Air France - KLM 2019 | 0.729 | 56% | 0% | 0% | 19% |
| Lufthansa 2013 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2014 | 0.975 | 0% | 0% | 0% | 2% |
| Lufthansa 2015 | 1 | 0% | 0% | 0% | 0% |
| Lufthansa 2016 | 1 | 2% | 0% | 0% | 0% |
| Lufthansa 2017 | 0.989 | 0% | 0% | 0% | 6% |
| Lufthansa 2018 | 0.994 | 0% | 1% | 0% | 2% |
| Lufthansa 2019 | 1 | 0% | 0% | 0% | 0% |
| Aegean 2013 | 0.999 | 5% | 0% | 0% | 0% |
| Aegean 2014 | 0.971 | 0% | 0% | 0% | 0% |
| Aegean 2015 | 0.930 | 3% | 0% | 0% | 0% |
| Aegean 2016 | 0.911 | 0% | 0% | 0% | 0% |
| Aegean 2017 | 0.948 | 7% | 0% | 0% | 0% |
| Aegean 2018 | 0.917 | 8% | 0% | 0% | 0% |
| Alitalia SAI Spa 2016 | 0.876 | 56% | 0% | 0% | 0% |
| Alitalia SAI Spa 2017 | 0.822 | 52% | 0% | 0% | 0% |
| Alitalia SAI Spa 2018 | 0.830 | 52% | 0% | 0% | 0% |
| SATA Internacional 2013 | 0.936 | 0% | 0% | 5% | 7% |
| SATA Internacional 2014 | 0.927 | 0% | 0% | 9% | 7% |
| SATA Internacional 2015 | 1 | 0% | 0% | 0% | 0% |
| SATA Internacional 2016 | 0.962 | 0% | 0% | 0% | 0% |
| SATA Internacional 2017 | 0.972 | 0% | 0% | 0% | 0% |
| SATA Internacional 2018 | 1 | 0% | 0% | 0% | 0% |
| SATA Air Açores 2013 | 1 | 0% | 0% | 0% | 0% |
| SATA Air Açores 2014 | 1 | 0% | 0% | 17% | 10% |
| SATA Air Açores 2015 | 1 | 0% | 0% | 0% | 0% |
| SATA Air Açores 2016 | 1 | 0% | 0% | 5% | 3% |
| SATA Air Açores 2017 | 1 | 0% | 0% | 0% | 0% |
| SATA Air Açores 2018 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2013 | 0.642 | 5% | 0% | 0% | 0% |
| Flybe 2014 | 0.720 | 0% | 11% | 0% | 0% |
| Flybe 2015 | 0.996 | 0% | 0% | 0% | 0% |
| Flybe 2016 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2017 | 1 | 0% | 0% | 0% | 0% |
| Flybe 2018 | 0.955 | 0% | 5% | 0% | 0% |

## Analysis 3: CRS efficiency scores

**Input:** Number of flights;

**Outputs:** Number of passengers, PLF (Passenger load factor).

***Table A.3.1 - Airlines Analysis 3: CRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 0.442 | 0.437 | 0.443 | 0.445 | 0.475 | 0.474 | - |
| Ryanair | 0.860 | 0.866 | 0.924 | 0.971 | 0.988 | 0.999 | 1.000 |
| Air France – KLM | 0.730 | 0.701 | 0.689 | 0.704 | 0.729 | 0.734 | 0.737 |
| Lufthansa | 0.565 | 0.588 | 0.596 | 0.597 | 0.637 | 0.678 | 0.685 |
| Aegean | 0.536 | 0.576 | 0.602 | 0.625 | 0.686 | 0.719 | - |
| Alitalia SAI S.p.A. | - | - | - | 0.615 | 0.618 | 0.617 | - |
| SATA Internacional | 0.937 | 0.982 | 1.000 | 0.962 | 0.924 | 0.927 | - |
| SATA Air Açores | 0.308 | 0.376 | 0.397 | 0.350 | 0.343 | 0.359 | - |
| Eastern Airways | 0.133 | 0.131 | 0.135 | 0.152 | 0.141 | 0.177 | - |
| Loganair | 0.130 | 0.126 | 0.125 | 0.131 | 0.121 | 0.123 | - |
| Flybe | 0.302 | 0.320 | 0.309 | 0.293 | 0.302 | 0.330 | - |

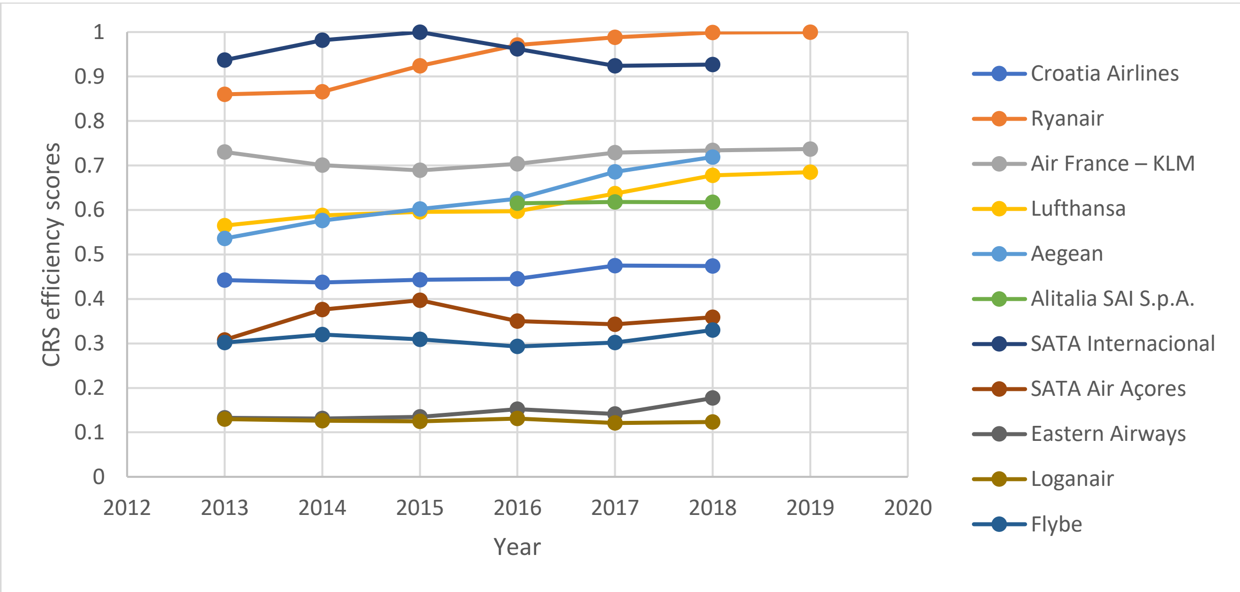


***Figure A.3.1 – Airline Analysis 3: CRS efficiency scores***

## Analysis 3: VRS efficiency scores

**Input:** Number of flights;

**Outputs:** Number of passengers, PLF (Passenger load factor).

***Table A.3.2 - Airlines Analysis 3: VRS efficiency scores***

| Airline/Group | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Croatia Airlines | 0.451 | 0.444 | 0.450 | 0.452 | 0.479 | 0.479 | - |
| Ryanair | 0.860 | 0.866 | 0.924 | 1.000 | 0.992 | 1.000 | 1.000 |
| Air France – KLM | 0.730 | 0.701 | 0.689 | 0.704 | 0.729 | 0.734 | 0.737 |
| Lufthansa | 0.566 | 0.588 | 0.597 | 0.597 | 0.637 | 0.678 | 1.000 |
| Aegean | 0.536 | 0.577 | 0.603 | 0.626 | 0.804 | 1.000 | - |
| Alitalia SAI S.p.A. | - | - | - | 0.615 | 0.619 | 0.617 | - |
| SATA Internacional | 0.948 | 0.988 | 1.000 | 0.969 | 0.935 | 0.939 | - |
| SATA Air Açores | 0.430 | 0.491 | 0.467 | 0.406 | 0.378 | 0.375 | - |
| Eastern Airways | 0.201 | 0.195 | 0.205 | 0.238 | 0.222 | 0.251 | - |
| Loganair | 0.161 | 0.150 | 0.143 | 0.140 | 0.130 | 0.132 | - |
| Flybe | 0.303 | 0.321 | 0.311 | 0.294 | 0.303 | 0.331 | - |

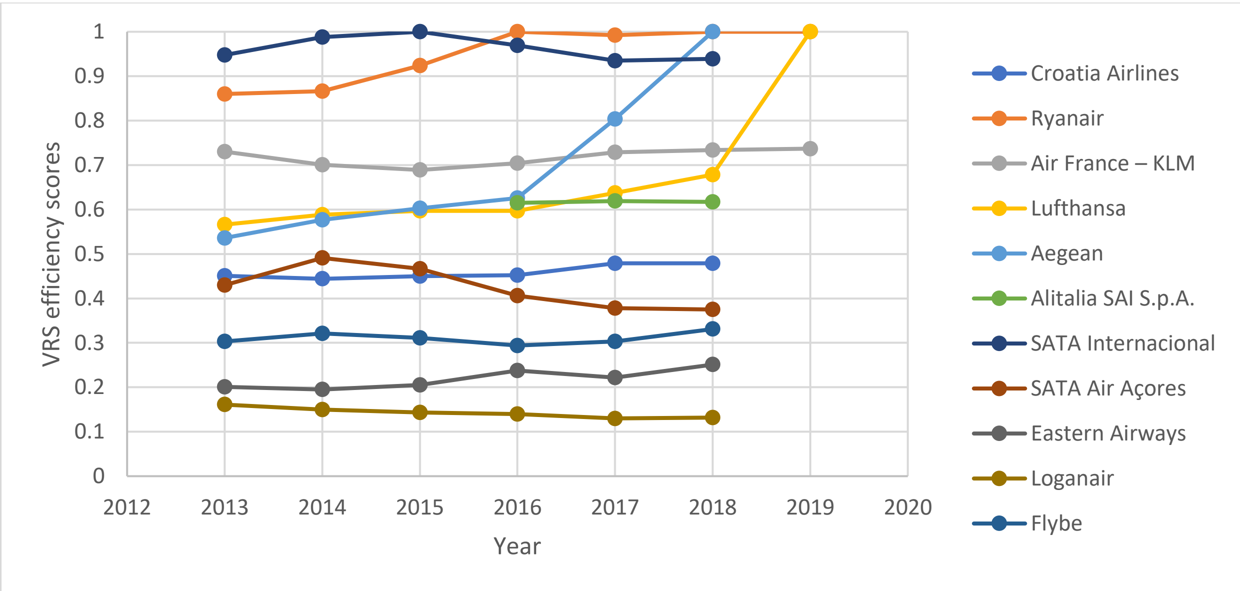


***Figure A.3.3 – Airline Analysis 3: VRS efficiency scores***

# Appendix B – PSO route performance analysis

The correspondence between the color and the operating airline is as follows:

- Route operated by **Croatia Airlines**
- Route operated by **Ryanair**
- Route operated by **Air France (group)**
- Route operated by **Olympic Air** (Aegean subsidiary)
- Route operated by **Alitalia SAI S.p.A.**
- Route operated by **SATA Internacional**
- Route operated by **SATA Air Açores**
- Route operated by **Eastern Airways**
- Route operated by **Flybe**
- Route operated by **Loganair**
- Other airlines operating

## Analysis 1: VRS efficiency scores

**Inputs:** Minimum number of annual seats required by the PSO, Amount of annual compensation;

**Outputs:** Annual seats offered on the PSO route, PSO passengers.

***Table B.1 - PSOs Analysis 1: VRS efficiency scores***

| | ICAO airport code | PTE (VRS) |
|---|---|---|
| 1 | LDDU-LDZA | 0.839 |
| 2 | LDSP-LDZA | 0.687 |
| 3 | LDZA-LDZA-LDPL | 0.349 |
| 4 | LDZA-LDSB | 1.000 |
| 5 | LDOS-LDDU | 1.000 |
| 6 | LDOS-LDSP | 1.000 |
| 7 | LDOS-LDZA | 0.278 |
| 8 | LDOS-LDPL-LDSP | 0.490 |
| 9 | LDOS-LDRI | 0.481 |
| 10 | LDRI-LDSP-LDDU | 0.471 |
| 11 | LCLK-EBBR | 1.000 |
| 12 | EFMA-ESSA | 0.372 |
| 13 | LFBA-LFPO | 0.483 |
| 14 | LFST-EHAM | 1.000 |
| 15 | LFST-LEMD | 0.479 |
| 16 | EIDW-EIFL | 0.490 |
| 17 | EIDW-EIKY | 0.496 |
| 18 | EICA-EIIM/ EIMN/ EIIR | 0.465 |
| 19 | LIEA-LIML | 0.865 |
| 20 | LIEA-LIRF | 0.563 |
| 21 | LIEO-LIML | 0.813 |
| 22 | LIEO-LIRF | 0.663 |
| 23 | LIEE-LIML | 0.950 |
| 24 | LIEE-LIRF | 1.000 |
| 25 | LICD-LICC | 0.211 |
| 26 | LICD-LICJ | 0.220 |
| 27 | LICG-LICJ | 0.193 |
| 28 | LICG-LICT | 0.181 |
| 29 | LICG-LICC | 0.178 |
| 30 | LPBG- LPVR-LPVZ-LPPM-LPCS | 0.273 |
| 31 | LPMA-LPPD | 0.522 |
| 32 | LPMA-LPPS | 0.355 |
| 33 | LPPT-LPHR | 0.463 |
| 34 | LPPT-LPPI | 0.545 |
| 35 | LPPT-LPAZ | 0.703 |
| 36 | LPCR-LPFL | 0.477 |
| 37 | LPHR-LPCR | 0.451 |
| 38 | LPHR-LPFL | 0.472 |

| | ICAO airport code | PTE (VRS) |
|---|---|---|
| 39 | LPPD-LPFL | 1.000 |
| 40 | LPPD-LPHR | 0.812 |
| 41 | LPPD-LPPI | 1.000 |
| 42 | LPPD-LPAZ | 0.669 |
| 43 | LPPD-LPSJ | 1.000 |
| 44 | LPPD-LPLA | 1.000 |
| 45 | LPLA-LPFL | 0.406 |
| 46 | LPLA-LPGR | 0.658 |
| 47 | LPLA-LPHR | 0.709 |
| 48 | LPLA-LPPI | 0.540 |
| 49 | LPLA-LPSJ | 0.549 |
| 50 | LEPA-LEIB | 1.000 |
| 51 | LEPA-LEMH | 0.711 |
| 52 | GCLP-GCHI | 0.779 |
| 53 | GCLP-GCTS | 1.000 |
| 54 | GCLP-GCFV | 0.621 |
| 55 | GCLP-GCRR | 0.870 |
| 56 | GCLP-GCXO | 1.000 |
| 57 | GCLP-GCLA | 0.723 |
| 58 | GCGM-GCXO | 0.727 |
| 59 | GCXO-GCHI | 0.719 |
| 60 | GCXO-GCFV | 0.856 |
| 61 | GCXO-GCRR | 0.782 |
| 62 | GCXO-GCLA | 0.710 |
| 63 | ESNX-ESSA | 0.376 |
| 64 | ESNG-ESSA | 0.358 |
| 65 | ESNL-ESSA | 0.330 |
| 66 | ESNV-ESSA | 0.303 |
| 67 | ESUT-ESSA | 0.251 |
| 68 | ESND-ESSA | 0.625 |
| 69 | ESST-ESSA | 0.493 |
| 70 | ESOH-ESSA | 0.526 |
| 71 | ESUP-ESPA | 0.330 |
| 72 | ESNZ-ESNU | 0.353 |
| 73 | EGFF-EGOV | 0.319 |
| 74 | EGHQ-EGLL | 0.492 |
| 75 | EGPN-EGSS | 0.345 |
| 76 | EGAE-EGSS | 0.441 |

*Table B.2 - Slack variables and improvement potential (PSOs Analysis 1)*

| | Route (ICAO airport code) | PTE (VRS) | Minimum number of annual seats required by the PSO | Amount of annual compensation (thousands €) | Actual annual seats offered on the PSO route | PSO passengers (2018) |
|---|---|---|---|---|---|---|
| 1 | LDDU-LDZA | 0.839 | 0% | 34% | 0% | 0% |
| 2 | LDSP-LDZA | 0.687 | 0% | 34% | 0% | 6% |
| 3 | LDZA-LDZA-LDPL | 0.349 | 0% | 0% | 0% | 165% |
| 4 | LDZA-LDSB | 1 | 0% | 0% | 0% | 0% |
| 5 | LDOS-LDDU | 1 | 0% | 0% | 0% | 0% |
| 6 | LDOS-LDSP | 1 | 0% | 0% | 0% | 0% |
| 7 | LDOS-LDZA | 0.278 | 0% | 0% | 0% | 200% |
| 8 | LDOS-LDPL-LDSP | 0.490 | 0% | 0% | 19% | 16% |
| 9 | LDOS-LDRI | 0.481 | 0% | 0% | 20% | 118% |
| 10 | LDRI-LDSP-LDDU | 0.471 | 0% | 13% | 23% | 49% |
| 11 | LCLK-EBBR | 1 | 0% | 0% | 0% | 0% |
| 12 | EFMA-ESSA | 0.372 | 0% | 0% | 0% | 64% |
| 13 | LFBA-LFPO | 0.483 | 0% | 0% | 0% | 12% |
| 14 | LFST-EHAM | 1 | 0% | 0% | 0% | 0% |
| 15 | LFST-LEMD | 0.479 | 0% | 0% | 0% | 14% |
| 16 | EIDW-EIFL | 0.490 | 0% | 0% | 0% | 39% |
| 17 | EIDW-EIKY | 0.496 | 0% | 0% | 0% | 25% |
| 18 | EICA-EIIM/ EIMN/ EIIR | 0.465 | 0% | 0% | 0% | 46% |
| 19 | LIEA-LIML | 0.865 | 0% | 26% | 0% | 0% |
| 20 | LIEA-LIRF | 0.563 | 0% | 34% | 0% | 4% |
| 21 | LIEO-LIML | 0.813 | 0% | 53% | 0% | 5% |
| 22 | LIEO-LIRF | 0.663 | 0% | 31% | 0% | 2% |
| 23 | LIEE-LIML | 0.950 | 0% | 95% | 9% | 0% |
| 24 | LIEE-LIRF | 1 | 0% | 0% | 0% | 0% |
| 25 | LICD-LICC | 0.211 | 0% | 0% | 0% | 12% |
| 26 | LICD-LICJ | 0.220 | 0% | 0% | 0% | 37% |
| 27 | LICG-LICJ | 0.193 | 0% | 0% | 0% | 44% |
| 28 | LICG-LICT | 0.181 | 0% | 0% | 0% | 70% |
| 29 | LICG-LICC | 0.178 | 0% | 0% | 0% | 52% |
| 30 | LPBG- LPVR-LPVZ-LPPM-LPCS | 0.273 | 0% | 0% | 0% | 0% |
| 31 | LPMA-LPPD | 0.522 | 0% | 0% | 0% | 4% |
| 32 | LPMA-LPPS | 0.355 | 0% | 0% | 0% | 105% |
| 33 | LPPT-LPHR | 0.463 | 0% | 0% | 10% | 0% |
| 34 | LPPT-LPPI | 0.545 | 0% | 0% | 0% | 13% |
| 35 | LPPT-LPAZ | 0.703 | 0% | 0% | 33% | 127% |
| 36 | LPCR-LPFL | 0.477 | 0% | 26% | 0% | 198% |
| 37 | LPHR-LPCR | 0.451 | 0% | 13% | 0% | 12% |
| 38 | LPHR-LPFL | 0.472 | 0% | 0% | 0% | 1% |
| 39 | LPPD-LPFL | 1 | 0% | 0% | 0% | 0% |
| 40 | LPPD-LPHR | 0.812 | 0% | 0% | 6% | 0% |

*Table B.2 - Slack variables and improvement potential (PSOs Analysis 1) (continuation)*

| | Route (ICAO airport code) | PTE (VRS) | Minimum number of annual seats required by the PSO | Amount of annual compensation (thousands €) | Actual annual seats offered on the PSO route | PSO passengers (2018) |
|---|---|---|---|---|---|---|
| 41 | LPPD-LPPI | 1 | 0% | 0% | 0% | 0% |
| 42 | LPPD-LPAZ | 0.669 | 0% | 0% | 0% | 0% |
| 43 | LPPD-LPSJ | 1 | 0% | 0% | 0% | 0% |
| 44 | LPPD-LPLA | 1 | 0% | 0% | 0% | 0% |
| 45 | LPLA-LPFL | 0.406 | 0% | 0% | 0% | 0% |
| 46 | LPLA-LPGR | 0.658 | 0% | 0% | 0% | 20% |
| 47 | LPLA-LPHR | 0.709 | 0% | 0% | 0% | 4% |
| 48 | LPLA-LPPI | 0.540 | 0% | 0% | 0% | 3% |
| 49 | LPLA-LPSJ | 0.549 | 0% | 0% | 0% | 0% |
| 50 | LEPA-LEIB | 1 | 0% | 0% | 0% | 0% |
| 51 | LEPA-LEMH | 0.711 | 0% | 0% | 0% | 10% |
| 52 | GCLP-GCHI | 0.779 | 0% | 0% | 0% | 13% |
| 53 | GCLP-GCTS | 1 | 0% | 0% | 0% | 0% |
| 54 | GCLP-GCFV | 0.621 | 0% | 0% | 0% | 2% |
| 55 | GCLP-GCRR | 0.870 | 0% | 0% | 4% | 0% |
| 56 | GCLP-GCXO | 1 | 0% | 0% | 0% | 0% |
| 57 | GCLP-GCLA | 0.723 | 0% | 0% | 13% | 0% |
| 58 | GCGM-GCXO | 0.727 | 0% | 0% | 9% | 0% |
| 59 | GCXO-GCHI | 0.719 | 0% | 0% | 9% | 0% |
| 60 | GCXO-GCFV | 0.856 | 0% | 0% | 16% | 0% |
| 61 | GCXO-GCRR | 0.782 | 0% | 0% | 17% | 0% |
| 62 | GCXO-GCLA | 0.710 | 0% | 0% | 0% | 0% |
| 63 | ESNX-ESSA | 0.376 | 0% | 0% | 0% | 64% |
| 64 | ESNG-ESSA | 0.358 | 0% | 0% | 0% | 97% |
| 65 | ESNL-ESSA | 0.330 | 0% | 0% | 0% | 68% |
| 66 | ESNV-ESSA | 0.303 | 0% | 0% | 0% | 31% |
| 67 | ESUT-ESSA | 0.251 | 0% | 0% | 0% | 34% |
| 68 | ESND-ESSA | 0.625 | 0% | 0% | 0% | 161% |
| 69 | ESST-ESSA | 0.493 | 0% | 0% | 0% | 85% |
| 70 | ESOH-ESSA | 0.526 | 0% | 0% | 0% | 71% |
| 71 | ESUP-ESPA | 0.330 | 0% | 0% | 0% | 123% |
| 72 | ESNZ-ESNU | 0.353 | 0% | 0% | 0% | 69% |
| 73 | EGFF-EGOV | 0.319 | 0% | 0% | 0% | 0% |
| 74 | EGHQ-EGLL | 0.492 | 0% | 0% | 0% | 6% |
| 75 | EGPN-EGSS | 0.345 | 0% | 0% | 0% | 24% |
| 76 | EGAE-EGSS | 0.441 | 0% | 0% | 0% | 0% |

## Analysis 2: VRS efficiency scores

**Input:** Frequencies;

**Outputs:** PSO passengers; PLF.

***Table B.3 - PSOs Analysis 2: VRS efficiency scores***

| | ICAO airport code | PTE (VRS) |
|---|---|---|
| 1 | LDDU-LDZA | 0.394 |
| 2 | LDSP-LDZA | 0.304 |
| 3 | LDZA-LDZD-LDPL | 0.083 |
| 4 | LDZA-LDSB | 0.517 |
| 5 | LDOS-LDDU | 1.000 |
| 6 | LDOS-LDSP | 1.000 |
| 7 | LDOS-LDZA | 0.083 |
| 8 | LDOS-LDPL-LDSP | 0.250 |
| 9 | LDOS-LDRI | 0.250 |
| 10 | LDRI-LDSP-LDDU | 0.250 |
| 11 | LCLK-EBBR | 1.000 |
| 12 | EEKA-EETN | 0.094 |
| 13 | EEKE-EEPU - EERU | 1.000 |
| 14 | EFHK-EFSA | 0.055 |
| 15 | EFMA-ESSA | 0.063 |
| 16 | LFRB-LFEC | 0.050 |
| 17 | SOCA-SOGS | 0.167 |
| 18 | SOCA-SOOA | 0.145 |
| 19 | SOCA-SOOS | 1.000 |
| 20 | SOOM-SOGS | 0.171 |
| 21 | LFBH-LFBI-LFLL | 0.361 |
| 22 | LFBA-LFPO | 0.851 |
| 23 | LFSL-LFPO | 0.081 |
| 24 | LFCK-LFPO | 0.070 |
| 25 | LFBT-LFPO | 0.666 |
| 26 | LFHP-LFPO | 0.054 |
| 27 | LFBL-LFPO | 0.050 |
| 28 | LFBL-LFLL | 0.064 |
| 29 | LFCR-LFPO | 0.087 |
| 30 | LFST-LEMD | 0.414 |
| 31 | LFKJ-LFML | 0.520 |
| 32 | LFKF-LFML | 0.334 |
| 33 | LFKJ-LFMN | 0.224 |
| 34 | LFKF-LFMN | 0.195 |
| 35 | LFKB-LFML | 0.503 |
| 36 | LFKC-LFML | 0.198 |
| 37 | LFKB-LFMN | 0.209 |
| 38 | LFKC-LFMN | 0.101 |
| 39 | LFKB-LFPO | 1.000 |
| 40 | LFKC-LFPO | 0.784 |
| 41 | LGAL-LGST | 0.250 |
| 42 | LGAV-LGPL | 0.760 |
| 43 | LGAV-LGKY | 0.477 |
| 44 | LGAV-LGKZ- LGKA | 0.117 |
| 45 | LGAV-LGSY | 0.440 |
| 46 | LGPZ-LGST | 0.250 |
| 47 | LGKR-LGPZ-LGKF-LGZA | 0.214 |
| 48 | LGLM-LGMT-LGHI-LGSM-LGRP | 0.214 |
| 49 | LGRP-LGKP-LGKS | 0.117 |
| 50 | LGRP-LGKJ | 0.119 |
| 51 | LGRP-LGKO-LGKY-LGLE-LGPL | 0.214 |
| 52 | LGTS-LGKR | 0.250 |
| 53 | LGTS-LGLM - LGIK | 0.115 |
| 54 | LGTS-LGSM | 0.217 |
| 55 | LGTS-LGSY | 0.250 |
| 56 | LGTS-LGKL | 1.000 |
| 57 | EIDW-EIFL | 0.083 |
| 58 | EIDW-EIKY | 0.126 |
| 59 | EICA-EIIM/ EIMN/ EIIR | 0.027 |
| 60 | LIEA-LIML | 0.615 |
| 61 | LIEA-LIRF | 0.483 |
| 62 | LIEO-LIML | 0.676 |
| 63 | LIEO-LIRF | 0.539 |
| 64 | LIEE-LIML | 0.809 |
| 65 | LIEE-LIRF | 1.000 |
| 66 | LICD-LICC | 0.084 |
| 67 | LICD-LICJ | 0.049 |
| 68 | LICG-LICJ | 0.052 |

*Table B.3 - PSOs Analysis 2: VRS efficiency scores (continuation)*

| | ICAO airport code | PTE (VRS) |
|---|---|---|
| 69 | LICG-LICT | 0.051 |
| 70 | LICG-LICC | 0.169 |
| 71 | LPBG-LPVR-LPVZ-LPPM-LPCS | 0.071 |
| 72 | LPMA-LPPD | 1.000 |
| 73 | LPMA-LPPS | 0.076 |
| 74 | LPPT-LPHR | 0.928 |
| 75 | LPPT-LPPI | 0.471 |
| 76 | LPPT-LPAZ | 0.330 |
| 77 | LPCR-LPFL | 0.167 |
| 78 | LPHR-LPCR | 0.148 |
| 79 | LPHR-LPFL | 0.116 |
| 80 | LPPD-LPFL | 0.541 |
| 81 | LPPD-LPHR | 0.249 |
| 82 | LPPD-LPPI | 0.359 |
| 83 | LPPD-LPAZ | 0.214 |
| 84 | LPPD-LPSJ | 0.441 |
| 85 | LPPD-LPLA | 0.265 |
| 86 | LPLA-LPFL | 0.157 |
| 87 | LPLA-LPGR | 0.154 |
| 88 | LPLA-LPHR | 0.181 |
| 89 | LPLA-LPPI | 0.138 |
| 90 | LPLA-LPSJ | 0.178 |
| 91 | LEAM-LEZL | 0.090 |
| 92 | LEPA-LEIB | 0.676 |
| 93 | LEPA-LEMH | 0.448 |
| 94 | GCLP-GCHI | 0.159 |
| 95 | GCLP-GCTS | 0.443 |
| 96 | GCLP-GCFV | 0.299 |
| 97 | GCLP-GCRR | 0.475 |
| 98 | GCLP-GCXO | 0.544 |
| 99 | GCLP-GCLA | 0.333 |

| | ICAO airport code | PTE (VRS) |
|---|---|---|
| 100 | GCGM-GCLP | 0.059 |
| 101 | GCGM-GCXO | 0.129 |
| 102 | GCXO-GCHI | 0.313 |
| 103 | GCXO-GCFV | 0.481 |
| 104 | GCXO-GCRR | 0.364 |
| 105 | GCXO-GCLA | 0.366 |
| 106 | ESNX-ESSA | 0.062 |
| 107 | ESNG-ESSA | 0.067 |
| 108 | ESNL-ESSA | 0.059 |
| 109 | ESNV-ESSA | 0.055 |
| 110 | ESUT-ESSA | 0.067 |
| 111 | ESND-ESSA | 0.055 |
| 112 | ESST-ESSA | 0.050 |
| 113 | ESOH-ESSA | 0.050 |
| 114 | ESUP-ESPA | 0.045 |
| 115 | ESNZ-ESNU | 0.054 |
| 116 | EGFF-EGOV | 0.081 |
| 117 | EGPF-EGBR | 0.050 |
| 118 | EGPF-EGEC | 0.054 |
| 119 | EGPF-EGPU | 0.047 |
| 120 | EGEO-EGEL | 0.125 |
| 121 | EGEO-EGEY | 0.125 |
| 122 | EGEO-EGPU | 0.125 |
| 123 | EGEL-EGPU | 0.125 |
| 124 | EGPO-EGPL | 0.071 |
| 125 | EGET-EGEF | 0.045 |
| 126 | EGET-EG42 | 0.077 |
| 127 | EGET-EG79 | 0.250 |
| 128 | EGHQ-EGLL | 0.349 |
| 129 | EGPN-EGSS | 0.067 |
| 130 | EGAE-EGSS | 0.191 |

*Table B.4 - PSOs Analysis 2: Routes with the worst pure technical efficiency*

| Member State | Airport | Airport | Airlines operating | PTE (VRS) |
|---|---|---|---|---|
| **Croatia** | Zagreb | Zadar - Pula | Croatia Airlines | 0.083 |
| **Croatia** | Osijek | Zagreb | Trade Air | 0.083 |
| **Estonia** | Kärdla | Tallinn | Transavia-baltika | 0.094 |
| **Finland** | Helsinki | Savonlinna | Akciju sabiedriba "RAF AVIA" (LV) or Budapest Aircraft Service (BASEe), (HU) | 0.055 |
| **Finland** | Mariehamn (Åland) | Stockholm | Danish Air Transport A/S | 0.063 |
| **France** | Brest (Guipavas) | Ouessant | Finist'Air | 0.050 |
| **France** | Brive-La- Gaillarde (Souillac) | Paris (Orly) | HOP*!* | 0.081 |
| **France** | Castres (Mazamet) | Paris (Orly) | Air France | 0.070 |
| **France** | Le Puy-en-Velay (Loudes) | Paris (Orly) | Twin Jet | 0.054 |
| **France** | Limoges (Bellegarde) | Paris (Orly) | Chalair Aviation | 0.050 |
| **France** | Limoges (Bellegarde) | Lyon (Saint- Exupéry) | Chalair Aviation | 0.064 |
| **France** | Rodez (Marcillac) | Paris (Orly) | Flybe | 0.087 |
| **Ireland** | Dublin | Donegal | Stobart Air | 0.083 |
| **Ireland** | Connemara | Aran Islands (Inis Mor/Inis Meain/Inis Oirr) | Galway Aviation Services Ltd., IE | 0.027 |
| **Italy** | Lampedusa | Catania | Danish Air Transport A/S | 0.084 |
| **Italy** | Lampedusa | Palermo | Danish Air Transport A/S | 0.049 |
| **Italy** | Pantelleria | Palermo | Danish Air Transport A/S | 0.052 |
| **Italy** | Pantelleria | Trapani | Danish Air Transport A/S | 0.051 |
| **Portugal** | Bragança -Vila Real - Viseu - Portimão | Cascais | AEROVIP, S.A. | 0.071 |
| **Portugal** | Funchal | Porto Santo | Binter Canarias | 0.076 |
| **Spain** | Almeria | Sevilla | Air Nostrum | 0.090 |
| **Spain** | La Gomera | Gran Canaria | Binter group (Binter, Canarias airlines) | 0.059 |
| **Sweden** | Arvidsjaur | Stockholm/ Arlanda | Regional Jet oü | 0.062 |
| **Sweden** | Gällivare | Stockholm/ Arlanda | Regional Jet oü | 0.067 |
| **Sweden** | Lycksele | Stockholm/ Arlanda | Amapola | 0.059 |
| **Sweden** | Vilhelmina | Stockholm/ Arlanda | Amapola | 0.055 |
| **Sweden** | Hemavan | Stockholm/ Arlanda | Amapola | 0.067 |
| **Sweden** | Sveg | Stockholm/ Arlanda | Flexflight ApS | 0.055 |
| **Sweden** | Torsby | Stockholm/ Arlanda | Flexflight ApS | 0.050 |
| **Sweden** | Hagfors | Stockholm/ Arlanda | Flexflight ApS | 0.050 |
| **Sweden** | Pajala | Luleå | Jonair AB | 0.045 |
| **Sweden** | Östersund | Umeå | Flexflight ApS | 0.054 |
| **UK** | Cardiff | RAF Valley, Anglesey | Eastern Airways (UK) Ltd and Air Kilroe Ltd t/a Eastern Airway | 0.081 |
| **UK** | Glasgow (International) | Barra | Loganair | 0.050 |
| **UK** | Glasgow (International) | Campbeltown | Loganair | 0.054 |
| **UK** | Glasgow (International) | Tiree | Loganair | 0.047 |
| **UK** | Stornoway | Benbecula | Loganair | 0.071 |
| **UK** | Tingwall / Sumburgh (Sat) | Fair Isle | Airtask (formerly Directflight) | 0.045 |
| **UK** | Tingwall | Foula | Airtask (formerly Directflight) | 0.077 |
| **UK** | Dundee | London Stansted | Loganair | 0.067 |