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Airport classification and functionality within the European network

by

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Abstract

This paper is meant to provide an insight into the roles and characteristics of the different typologies of airports by detailing a functional framework of European airports through the analysis of their distinctive features and interconnecting network. The first part of the work will focus on the classification of airports and their peculiarities following the most recent developments in this sector. The analysis will then turn to the methodology employed to verify the existence of subsystems (or modules) of high interconnectivity within the European aviation network. The classification hereby provided will therefore define the airports both as separate entities with specific characteristics and as parts of a particular network. The results will lead to the identification of major groups gathering together a number of airports characterised by similar features and goals. This paper will also hint at the existence of a solid parallel network within Europe, consisting of so-called secondary airports interconnected by means of low-cost carriers. It should here be stressed that the late development of the European airport network has been prompted by market-driven pressures rather than by clear-cut domestic or European schemes.

Keywords: Cluster, Simulated annealing, airport network evolution

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1. Introduction

The recent deregulation and liberalization of air transport markets have greatly affected and transformed the entire sector. In Europe this process has been accompanied by a series of concomitant purposeful events which have strengthened its impact, namely the privatization of airlines and airports, the creation of a single air transport market and the massive development of the low-cost phenomenon. As a consequence, the roles played by airports and the distinctive features of the airport network have changed over the last ten years. Current European and also extra-European connectivity models testify that the once typical reality of a domestic hub playing a vital role in international connections is now past its best days, as tellingly corroborated by the distribution of the international traffic: in 1995 Fiumicino airport would transport 40% of all international passengers (data include charter airline traffic, which is generally more well-distributed among the different airports than scheduled airline traffic), while the three largest airports would carry 71.2% of passengers overall. In 2006 Fiumicino airport's share fell to 26%, while the three largest airports as a whole carried 57.2% of the international passenger traffic.

Most of the so-called secondary airports have lately undergone unprecedented growth and steadily gained primary importance, as may be said of London Stansted in Europe. Nonetheless, it is clear that the main features of said minor airports set them apart from those airports of similar size with a former history as hubs. The recent developments ask no doubt for further clarification on the typology of airports forming the network. The very concept of hub may assume different connotations in Europe: we may identify historic hub airports such as London Heathrow, Paris CDG/Rossy and Frankfurt, which are key airports for the diverse world alliances and their leading carriers; newly-conceived hub airports such as Munich, London Gatwick and Stansted, operated by specific airlines; and others such as Fiumicino and Malpensa airports which may hardly be said to belong to the hub category, though they are indeed achieving great results worldwide.

The target of this paper is to define with utmost accuracy the airport network and the airports' distinctive features, which may lead in turn to a better understanding of the undergoing development process of the airport network and possibly its future configuration. The emergence of new needs has contributed together with a series of newly-born peculiarities (such as may be the presence of low-cost operators) to the classification of airports based on their possible compatibility. We may just think here of the need to improve economic regulatory measures which may secure the harmonious development of the services offered to users (mobility, quality, prices), or else the need to assess the opportunities the different airport operators may gain from the existing network configuration.

The classification of airports into homogeneous groups represents a good starting point for the analysis of a variety of issues, be it the impact of air route deregulation, airport congestion, suitable development policies and regulatory norms, and airport *benchmarking* between comparable systems. Indeed, the categorization of airports provided by the European Community, which is basically dimensional (number of passengers or volume of freight transported), is notably a reference point for the assignment of funds relating to the creation of new routes (EC, 2005). The paramount importance of the issue and the unavailability of an easy solution is proved by the many consultations launched by the European Union as early as the Nineties (EC, 1999 and EC, 2003).

In order to evaluate the impact of liberalization in Europe, Graham (1998) identifies 7 *clusters* according to the main characteristics of the areas served (*leisure destinations – important metropolitan areas*) and their main role (*intercontinental hub – major regional airports*), highlighting at the same time the risk for some European areas to be peripheralized.

The classification is based not only on the infrastructural services offered by each airport, but also on the identification of homogeneous clusters within which airports are found to share similar traits relating to performance, operational activities and roles within their geographical context. The service provided by air transportation is based on airport interconnectivity, access to local markets and nodes of connections within the airport network. The very characteristics of the network and its nodes are fundamental in outlining the overall structure of the market. Our paper is here meant to be a further development of Burghouwt and Hakfoort's study (2001), which examines the development of the European network between 1990 and 1998 by way of the hierarchic cluster methodology, thus defining 4 groups of airports according to the variables of typology and number of connections. Other studies (see Guimerà et al., 2005) concentrate more on the very characteristics of the network and the interconnectivity between subgroups to prove that the dimensions of airports and their functions may be totally unrelated. Studies on airport competition such as Cranfield University's (ATG, 2002) show that the most popular variables for airport classification centre on 5 different aspects: size (number of passengers, volume of freight, range of air services), geographical position (i.e. proximity to the capital), role (intercontinental rather than local hub), ownership (private or public) and association with a specific network. The studies so far conducted suggest somehow the equal importance of the variables defining airports as specific entities and of those intended to stress their role within a given network.

Our paper belongs to this line of research and aims to assimilate the two types of variables mentioned above into the traditional methods of classification and cluster analysis.

2. Methodology of research

The peculiarity of this paper lies in its classification of European airports by means of an innovative methodology. More specifically, airports will be grouped not only according to their own particular features, such as the number of passengers or freight volume, the overall movements effected, the number of routes or airlines, the number of residents of the catchment area and their relative GDP, but also according to the roles they play within the network.

An innovative technique will divide the overall European network into modules with the aim to identify the main features of the airport system within which the single airports are to be found. The single modules are intended to group together airports with very strong links between them in terms of number of connections, while being more weakly connected to the rest of the network. The methodology used here is known as *simulated annealing* and was first conceived to study the diffusion of heat in a solid body; it was later employed to simplify networks made of thousands of elements (neural networks, calculator networks etc.) into relatively independent networks.

The function we will maximize in order to achieve the partition of the network is known as *modularity* M(P) of a partition P of the network (Guimerà et al., 2007) and is defined as follows:

$$M(P)=\sum_{s=1}^{N_m}\left[\frac{l_s}{L}-\left(\frac{d_s}{2L}\right)^2\right]$$

where N_m is the number of modules (< or = the number of elements within network N), L is the number of links within the network, l_s is the number of connections between the airports belonging to module s and d_s is the sum of the degrees (that is the number of departing flights) of the airports within module s. The objective of the maximization of function M leads to the identification of the optimal partition P into which the network is to be divided, that is the optimal number of modules $N_{m.}$

The objective function M(P) is at its highest when the network is partitioned into compact modules, that is when there are numerous connections between airports belonging to the same module. The same function would obviously be at its lowest with modules grouping together airports badly connected between them. The non-linearity of the objective function and the fact that the number of modules cannot be known beforehand do not allow the use of the traditional techniques of *clustering* (hierarchical *clustering* or *k-means clustering*) to solve the problem of the partition of the network into modules by way of maximization of the function M(P). Guimerà and Aramal (2005) demonstrated that the most suitable technique that may be used here is the *simulated annealing,* an algorithm generating a stochastic optimization research where the probability to deviate from maximum increase of the objective function is strictly dependent not only on the improvement given by a new solution, but also on the search time. For further information on this methodology please see Kirkpatrick et al. (1983).

The technique of *simulated annealing* has so far been applied to the airport system generically using the possible existence of an interconnection between airports as variable, thoroughly neglecting variables which may prove paramount in assessing the “strength” of the connections (i.e. the number of seats or the frequency of routes). Our paper aims to overcome this limit by including the variable of the number of seats per route into the algorithm of modularization.

The methodology hereby applied may therefore be divided into the following parts:

1) Partitioning of the European airport network into modules by means of the *simulated annealing* methodology.
2) Categorization of the modules according to their functions within the network: modules including airports of very small size may be vital in connecting remote areas with the rest of the network (as is the case in Norway and Sweden); modules featuring one large international airport connected with small-to-medium size airports (for example domestic hubs linked to other airports within the same country); modules grouping medium-to-large size airports situated in different countries. This kind of module represents a sort of high-connectivity system at a European level.
3) Once points 1 and 2 have been dealt with, every single airport will be classified according to both the module typology and traditional standards; the traditional variables distinctive of each and every airport (number of passengers, movements etc.) will thus be examined with the employment of clustering techniques (hierarchical clustering).

As a result, the final classification of European airports will take into due account their role within the network, as may be identified through the analysis of the kind of module they are found to belong to.

3. Cluster analysis

Clustering techniques aim to identify groups sharing similar features. The analysis carried out on European airports has primarily focused on the role they play within the airport system and the relative homogeneous elements. The variables that could be identified have been grouped into 5 categories:

- Dimensional. The role and importance of an airport are undoubtedly related to its traffic volume. The three main variables are: the number of seats available on scheduled flights (seats / day), the number of daily flights (flights / day) and the number of destinations served (dest.). Although there is a correlation structure between these variables, they subtly emphasize different aspects of the dimensional variable, namely intensity, density and scope of the service offered.
- Destination of the connections. This variable helps classify the airport as an intercontinental gateway rather than a domestic connecting node. The analysis focuses in particular on the percentage of destinations offered within the EU (% EU dest) rather than domestic destinations (% dom dest). One more variable has been added to all the previous ones: it identifies the distribution of traffic among the routes made available and is meant to detect possible high points of concentration of the service. The variable employed here (route distribution) is the result of the HHI index, calculated as the sum of the squares of the number of seats offered on each route in relation to the total number of seats offered by the airport, divided by the same index as may be obtained hypothesizing an equal distribution of the number of seats offered among all the routes available within the same airport. The index thus shows a "relative" distribution of the routes, mitigated in that its dimensions are strictly dependent on the number of routes offered.
- Variables of connectivity: show the potentiality of an airport as intermediate connection. The variables used here are the so-called betweenness (*betw*) and limited percentage (*lim %*). The former is given by the number of times per day the airport works as intermediate connection between two airports linked through optimal connectivity, while the latter yields the percentage of times the airport cannot be bypassed through routes of similar duration (for further information see Malighetti et. al., 2007). The two variables stress the potentiality for interconnectivity of the airport and the importance of the airport as intermediate connection.
- Typology of service: given the peculiarities of low-cost airlines, this variable has been conceived to centre on the volume of seats offered by said airlines (*% low cost*). The aim is to examine a *point-to-point* connecting structure, where the airports' role is quite unlike the *hub-and-spoke* structure's. The lack of a coherent definition of "low-cost" carrier has suggested the use of the list drawn by Eurocontrol (EU, 2007). It should be remembered here that the role of the airport is influenced by its importance within the network of the different airlines. To this end, the variable "base" is meant to show the number of airlines considering one airport as their main reference[2] (calculated as percentage of the overall number of seats available with one airline).

[2] The main airport of reference thus determined may not coincide with the main logistic base of the carrier.

Table 1 shows the descriptive analysis for the different variables surveyed.

	n° dest	Seats / day	Flights / day	% EU dest	% Dom dest	Route distr.	Betweenness	% Lim	% Low cost	n° Bases
Average	19.7	2,825.7	22.4	94.7%	59.1%	1.83	104	49%	26%	0.29
Deviation Std.	34.3	7,262.2	47.4	11.4%	39.4%	1.00	329	41%	34%	0.73
25° percentile	21.0	2,065.1	19.9	100.0%	100.0%	2.22	38	84%	49%	-
75° percentile	2.0	90.3	1.9	96.0%	20.0%	1.08	-	0%	0%	-

Table 1. Descriptive statistics of the variables used in cluster analysis.

For their suitability to the characteristics of the airport network, the techniques of hierarchical clustering have been employed here. For further information on these techniques please refer to Everitt (2001). The method of aggregation we have chosen is the so-called "Ward linkage", which employs as its aggregation criteria the minimization of the sum of the squares of the distances between airports belonging to the same cluster. Unlike the Average Linkage, the Ward Linkage method tends to originate slightly more spherical clusters and consequently can identify clusters for medium-size airports as well. The application of the Average Linkage method instead, although it may generally show a higher cophenetic correlation coefficient, generates a number of clusters formed by singletons or single observations. The optimal number of clusters is 8 as suggested by the structure of the Dendrogram (figure 1) and further confirmed by the Duda/Hart index (table 2).

Duda/Hart test								
N° clusters	Je(2)/Je(1)	T-squared	N° clusters	Je(2)/Je(1)	T-squared	N° clusters	Je(2)/Je(1)	T-squared
1	0.755	145.2	6	0.782	26.0	11	0.619	41.7
2	0.531	188.6	7	0.662	24.5	12	0.747	14.8
3	0.740	66.7	**8**	0.622	**13.3**	13	0.754	19.5
4	0.812	53.7	9	0.724	29.2	14	0.630	8.2
5	0.781	38.9	10	0.726	35.4	15	0.715	15.4

Table 2. Results of the Duda/Hart test for the assessment of the optimal number of clusters. The number is given by the growth of the T-square statistics as a function of the number f clusters.

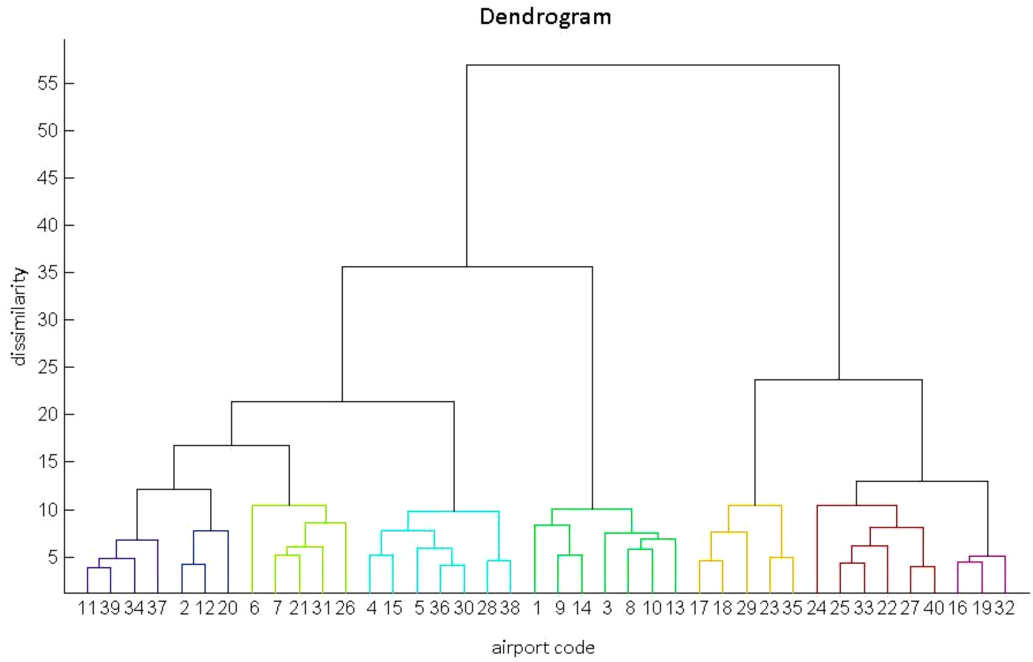

Figure 1. Dendrogram showing the "Ward linkage" method as applied to the sample of airports considered (467). Different colours have been used for the diverse clusters. The nodes represent the levels of dissimilarity (or the "distance") between the two subgroups deriving from the node.

Table 3 and figure 2 show the average values of the different clusters for all the variables analysed. A more detailed statistical analysis is provided in appendices A and B. The average silhouette width (Kaufman and Rousseeuw, 1990) of each and every cluster proves to be a good measure of the strength of clustering results (see Figure 3). Silhouette values show to what extent airports within the same cluster are characterized by proximity, while stressing their distance from airports belonging to different clusters. They can therefore lead to an analysis of how compact and significant the single clusters are, and what kind of role and general characteristics they may have in relation with a specific airport. An analysis of the values shows that clusters 5 and 6 are less homogeneous than the others.

Clust.	N° dest	Seats / day	Flights / day	% EU dest	% Dom dest	Route distr.	Between ness	Lim %	% Low cost	n° Bases
1	177.9	44,701.6	281.3	54.4%	11.8%	2.64	1,696	58%	10%	2.25
2	116.4	19,041.7	143.3	71.1%	13.1%	2.51	1,087	67%	27%	2.38
3	72.3	7,812.7	67.6	73.2%	17.0%	2.85	356	81%	30%	1.55
4	46.5	5,523.3	41.8	91.4%	15.2%	2.15	90	63%	75%	0.33
5	27.9	3,884.8	35.0	97.0%	44.6%	3.83	129	67%	25%	0.35
6	13.0	1,000.4	10.7	82.6%	28.2%	1.70	18	46%	19%	0.25
7	9.9	976.7	7.8	99.1%	21.8%	1.50	7	48%	76%	-
8	3.2	233.6	3.7	100.0%	93.9%	1.38	9	40%	6%	0.09

Table 3. Averages of the clusters identified.

A detailed review of the main characteristics of the clusters is provided herebelow:

Cluster n.1 comprises 8 airports which may be defined as worldwide hubs for their specific characteristics. The main airports served by worldwide alliances belong to this group (London Heathrow, Paris Charles de Gaulle, Amsterdam, Frankfurt as well as Rome Fiumicino). The airports grouped here share all similar dimensional characteristics, especially in terms of density (number of flights) and intensity (number of seats). They have a high percentage of overseas destinations and can offer a wide range of opportunities for interconnectivity (high betweenness ratio). These airports also work as main base for a variety of carriers and are characterised by the low presence of low-cost carriers.

Cluster n.2 (defined as "hub") groups 16 airports, namely former flag carriers' hubs (Athens, Vienna, Zurich, Brussels, Stockholm) and secondary medium or large-size hub airports (Gatwick, Orly). Malpensa and London Stansted also belong to this cluster. Unlike airports listed in cluster 1, those grouped here tend to favour European routes (on average 75% of the routes are within Europe) and are served by a variety of low-cost carriers.

Cluster n.3 is called "secondary intercontinental gate" and comprises 11 airports, among which Lisbon, Glasgow, Venice, Warsaw and Marseille airports. They are characterised by medium-size dimensions and offer a limited number of overseas destinations (less than 30% of the routes offered), with a visible concentration of traffic distribution over a limited number of destinations. Their role as intermediate connections (as assessed by a high limited % value) further confirms their main function as gates for local areas.

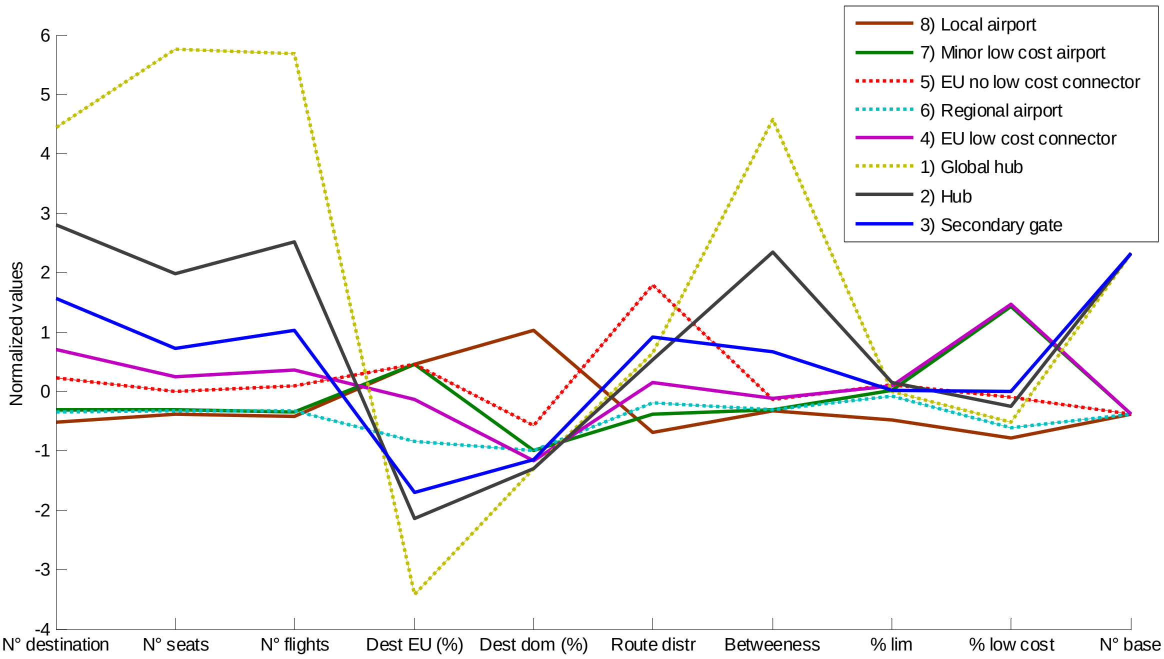

Figure 2. Normalized averages of the variables examined for the classification of the eight clusters.

Cluster n.4 groups together 33 airports with average traffic dimensions of 3-5 millions of passengers per year and are typically characterised by a high concentration of low-cost carriers (covering 75% of the seats offered on average). The main destinations are generally non-domestic and European: only 15% of the destinations are domestic, against an average of European destinations higher than 90%. This may be the result of the entry of low-cost carriers, which transformed secondary airports with limited local connections into structured realities belonging to a well-developed European network. Bergamo Orio al Serio, Ciampino and Pisa are the Italian airports belonging to this group.

Cluster n.5 gathers 46 airports and is also called "*no low-cost gate*" (with the term "gate" referring to the European rather than overseas market). As formerly said, this cluster seems to be less homogeneous than all the previous clusters described so far. Destinations here are almost always European. Low-cost carriers play a minor role and routes are mainly domestic and intended to connect secondary airports within the country. Some airports may be connecting points between hub and secondary airports, as may be evidenced by the average of the limited % index (up to 63%) and by the existence of a number of heavily flown routes along with less demanded flights (the index of distribution of the routes is higher here than in any other cluster). Linate, Palermo and Valencia airports are to be counted in this group.

Cluster n.6 is made of smaller, mainly regional airports. Like the previous cluster, it cannot be said to be remarkably compact.

Cluster n.7 consists of airports dimensionally similar to cluster n.6, but mainly characterised by the large presence of low-cost carriers, determining a wide offer of European rather than domestic destinations.

Cluster n.8 is the largest and is made of local airports (namely 238). Their offer is often limited to a restricted number of routes, only rarely more than 4 or 5, generally touching domestic destinations; low-cost carriers are seldom found to operate here and are absent in more than 75% of the airports listed in this category (as shown in Appendix A). This is the case of the Norwegian airports network and surprisingly of French secondary airports (25). Italian examples are Aosta, Crotone and Lampedusa airports.

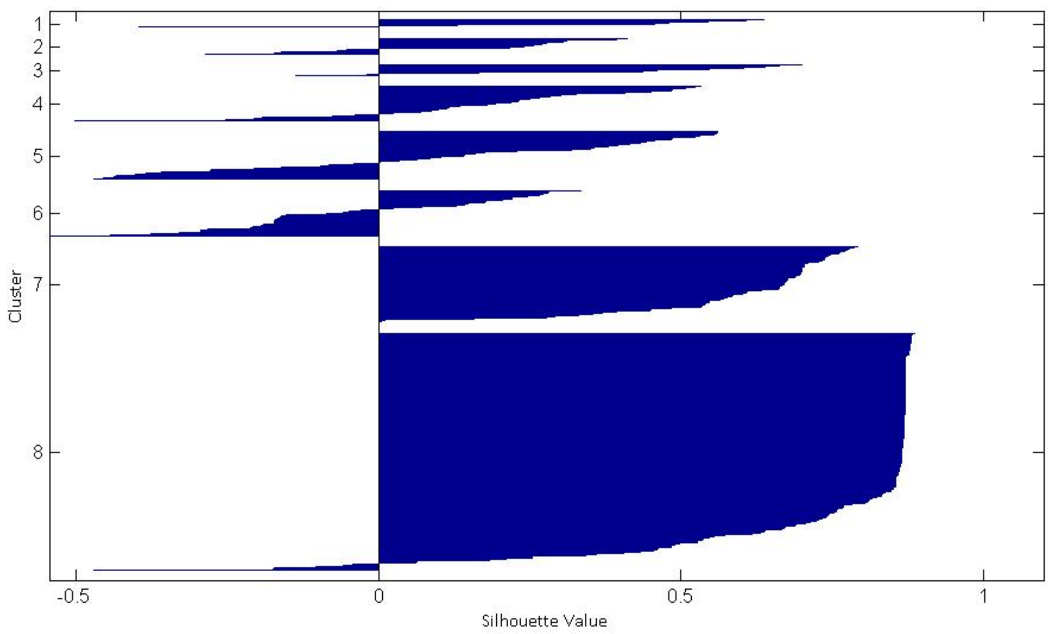

Figure 3. Silhouette values for each cluster. Unlike all other clusters, clusters 5 and 6 show a lower level of compactness.

To sum up all the above, cluster analysis may be said to lead to the following conclusions:

- Low-cost airports have been classified into two different clusters according to their dimensions.
- Major airports may be said to fall into three main categories: i) the big intercontinental hubs at the top; ii) airports offering sometimes even intercontinental services for a limited area, in an intermediary position; iii) hubs with a good intra-European network, but less apt than airports of cluster 1 to offer intercontinental services.

4. Results of the Simulated Annealing method

Interesting observations may be drawn by the results provided by the partition of the European network, formed by 467 airports with at least one passenger flight scheduled in Autumn 2007.

Table 4 shows the modules derived by use of the variable relating to the existence of connections. More specifically, 11 modules were generated, stretching from a maximum numerosity of 88 airports (first module) to a minimum of 7 (11th module). Major airports are those operating the highest number of connections (be it towards airports of the same module or outside), while the most important airports are the strongest within the module. The most important airports of each module may be regarded as “the new European capitals of air transportation”.

	No. airports	Major airport	Most important airport	% internal connections	HHI Airport	HHI Countries	Main country
1	88	London Stansted	London Stansted	50.7%	261	1,259	Sweden
2	70	Oslo	Oslo	54.4%	314	5,681	Norway
3	66	London Heathrow	Amsterdam-Schiphol	48.0%	263	5,754	United Kingdom
4	58	Frankfurt	Frankfurt	50.5%	270	3,111	Germany
5	50	Paris Charles De Gaulle	Paris Orly	45.2%	479	8,657	France
6	46	London Gatwick	Rome Fiumicino	37.5%	408	5,810	Italy
7	29	Athens Eleftherios	Athens Eleftherios	55.6%	1,344	9,474	Greece
8	25	Madrid Barajas	Barcelona	29.2%	728	8,756	Spain
9	19	Helsinki-Vantaa	Helsinki-Vantaa	46.2%	2,041	10,000	Finland
10	9	Nordela Airport	Nordela Airport	77.8%	1,505	10,000	Portugal
11	7	Reykjavik Domestic	Reykjavik Domestic	100.0%	1,837	10,000	Iceland

Table 4. Modules derived through simulated annealing, considering the existence of direct connections between the 467 airports examined.

Stansted airport is the major airport of the first module in terms of overall number of seats available. It is at the same time the airport that best contributes to the development of connections inside the module. More than 50% of the connections offered by all the airports of the module are towards other airports within the module itself. This percentage, which for some modules has been estimated to be even higher than 60%, gives a clear indication of the level of compactness of the group.

The HHI (concentration index) per airport and country[3] shows that the connections operated in this module are weakly centred around the airports and country of reference.

An in-depth analysis shows that, though Swedish airports are by large those with the highest number of connections within the module, several airports located outside Sweden are to be found here as well, namely 6 in Great Britain, 6 in France, 5 in Ireland, 4 in Spain and as many as 10 in Italy. This kind of "international" module may be regarded as typical of the airport network mainly operated by low-cost airlines. Rome Ciampino, Bergamo Orio al Serio and Pisa airports are all grouped here and are largely run by low-cost airlines.

The second module may be said to be headed by Oslo airport for numerosity; the majority of connections are operated between Norwegian airports, even though a number of airports from other countries are included here, namely 8 in Denmark, 6 in Sweden and the Reykjavik International airport in Iceland. The level of compactness of the module reaches 54.4% and is accompanied by a good concentration index per airport and per country. This "international" module comprises part of the Scandinavian territory, Denmark and provides access to Iceland.

The third module sees London Heathrow as its major airport with respect to numerosity, while the most important airport for connections within the module is Amsterdam-Schiphol. Four Irish airports, four Spanish, the majority of English airports, and all the Dutch airports are to be found here. This "international" module covers part of the network of the middle and northern Europe, mainly run by traditional airlines.

The fourth module is headed by Frankfurt airport for numerosity and includes the majority of German airports as well as airports in Austria, 9 in Spain and 9 in Greece. The module covers the airport network of central Europe managed by Lufthansa.

The other modules we identified may be regarded as prominently domestic and strictly relate to France, Italy, Greece, Spain, Finland, Portugal and Iceland.

Particular attention should be paid to module n.6, the most common in Italy. Fiumcino Rome is the major airport in this module, which includes several other Italian airports, notably the Milan-based airports of Malpensa and Linate, as well as Palermo, Catania and a number of other secondary airports mainly located in central and southern Italy. Rome Fiumicino may therefore be said to play a fundamental role as the coordinator of the Milan-Rome line, while representing the core of the

[3] Defined as $\sum_{i=1}^{n} s_i^{\,2}$ where s_i is the share of connections offered respectively by the single airports forming the module and the relative countries of reference.

Italian network, allowing domestic medium and small-sized airports to reach European as well as extra European destinations.

Malpensa plays here only a marginal role. While Fiumicino offers over 9% of connections within the module, Malpensa is limited to 5.5% (see table 6). This may be explained by the fact that Fiumicino has best developed its role as hub centre through a series of feedering connections with minor airports in central and southern Italy.

Interestingly, the biggest airport in the module headed by Fiumicino is London Gatwick, which provides for 5.5% of connections with other airports within the module. An explanation for this may be given by the fact that easyJet, Gatwick’s main airline company, offers a large number of flights towards Italy. In contrast with the policy adopted by other low-fare carriers such as Ryanair, serving mainly airports listed in module 1, easyJet has strategically decided to serve major airports, which won the airport its classification into a more “traditional” module.

An analysis of the group headed by Reykjavik Domestic airport shows that the percentage of internal connections equals 100%. This means that all the 7 Icelandic airports of the module are solely connected between them and have no kind of connection with the rest of Europe, be it direct or not. As a matter of fact, international connections towards and from Iceland are run at Reykjavik International airport, which is not linked to the other 7 domestic airports and indeed is part of the module headed by Norwegian and Danish airports.

The partition into modules shown in table 5 is basically built on the mere existence of connections between airports and gives similar weight to all sorts of connections, regardless of the number of seats available on the flights and their frequency. Otherwise said, the Fiumicino-Linate route, the second-largest in Europe for number of seats available daily, is appraised as the Catania-Lampedusa route, with its some tens of seats offered daily. In order to overcome this limitation, we have resorted to the simulated annealing technique, thus ranking the routes as more or less important on the grounds of the number of seats offered per week over the period considered. The modules thus obtained are shown in table 5.

	No. Airports	Major airport	Key airport	% Internal connections	HHI Airport	HHI Countries	Main Country
1	128	London Heathrow	Dublin	64.1%	289	3,119	United Kingdom
2	48	Paris Orly	Paris Orly	56.8%	1,491	9,968	France
3	48	Oslo	Oslo	74.1%	1,710	9,972	Norway
4	46	Frankfurt	Palma De Mallorca	55.8%	716	5,284	Germany
5	33	Stockholm-Arlanda	Stockholm-Arlanda	57.8%	1,822	9,730	Sweden
6	31	Athens Eleftherios	Athens Eleftherios	49.0%	2,350	8,354	Greece
7	31	Paris Charles De Gaulle	Rome Fiumicino	45.8%	1,127	8,505	Italy
8	30	Madrid Barajas	Madrid Barajas	47.7%	1,137	10,000	Spain
9	20	Helsinki-Vantaa	Helsinki-Vantaa	44.5%	2,761	10,000	Finland
10	17	Brussels National	Prague-Ruzyne	15.2%	1,627	1,948	Czech Republic
11	16	Lisbon	Lisbon	34.5%	1,678	9,366	Portugal
12	12	Copenhagen	Copenhagen	20.8%	3,002	7,939	Denmark
13	7	Reykjavik Domestic	Reykjavik Domestic	100.0%	3,201	10,000	Iceland

Table 5. Modules derived through the use of the simulated annealing method considering the seats available on the direct connections between the 467 airports examined.

On average, it may be easily said that the indicators of the "compactness" of the modules, calculated as the number of seats available on routes within the module divided by the total of seats offered in Europe, are much more meaningful than the indicators relating to the number of connections offered. Otherwise said, network segmentation is much more consistent when the number of seats made available (and not the mere number of connections offered) is taken into account. For this reason, we will henceforth rely on the modules derived from the number of seats offered in our comparison of the results with traditional clustering techniques.

Many of the modules derived, especially the mainly domestic, are similar to those previously analysed. For this reason special attention has been paid to the domestic modules of Sweden and Denmark.

A major difference concerns the first module and namely its numerosity. As a matter of fact, this module has remarkably grown from 88 to 128 airports. It still includes the major European low-cost airports, among which Stansted, Luton and Dublin, along with the major Italian low-cost airports, such as Ciampino, Orio al Serio and Pisa, but it now comprises more traditional airports located in Great Britain and Ireland as well. Taking the number of seats available as discriminant, the European low-cost and the English and Irish networks have merged. In other words, measuring the importance of the single routes against the number of seats offered, it may be said that the *point-to-point* network originated by the presence of low-cost operators has joined with the *hub-and-spoke* network of Great Britain and Ireland, which is mainly run by traditional airlines. This is hardly surprising, given that in these countries low-cost airlines operate along with traditional operators at the same airports.

Another point of dissimilarity is also provided by the so-called "Italian" module headed by Fiumicino. The number of seats made available reinforces the role of the Rome-based airport, with an offer of more than 25% of seats on connections within the module. By contrast Malpensa, with its share of 7.3% of seats offered, appears weaker, and so much so when compared with Linate and its share of 13.8% of the offer. The major airport is now the Paris-based airport Charles de Gaulle, while the London-based airport of Gatwick has been absorbed into module 1 together with the other English airports. Paris Charles de Gaulle cannot be included into module 2 with the other French airports because the latter are better integrated with the second-largest Paris-based airport of Orly. Charles de Gaulle has been classified within the "Italian" module thanks to its numerous connections with the major Italian airports, especially Fiumicino, Linate and Malpensa, and to its share of more than 8% of the overall number of seats offered within the module. This may be explained by the secondary role played by Alitalia within Skyteam, its worldwide alliance. Many intercontinental connections run by the alliance are as a matter of fact offered by Air France, with the airport of Charles de Gaulles as its hub. This is the reason why the Italian network appears to be well connected with the Paris-based airport, at least in terms of seats offered.

Table 6 illustrates the classification of all the Italian airports, in terms of number of connections and seats offered. A consideration of the network on the grounds of seats offered shows that, out of the 38 Italian airports taken into account, 27 belong to the module headed by Fiumicino, while 9 are part of the European module comprising the low-cost airports. Olbia and Rimini belong respectively to module 4, headed by Frankfurt (thanks to its numerous connections with some German airports), and the French module (thanks to its connections with Orly airport).

Together with Fiumicino (25.4%), Linate (13.8%) and Malpensa (7.3%), the Italian airports headed by Fiumicino which most contribute to the number of seats offered within the module are Catania (6.2%), Palermo (5.8%), Naples (5.2%) and Venice (4.1%).

The Italian airports with the largest number of seats offered within the low-cost module (module 1) are, in order of importance, Rome Ciampino (1.6%), Pisa (1.3%) and Bergamo Orio al Serio (1.2%).

		Modules derived from the existence of connections			Modules derived from the number of seats offered		
Code	Airport	No. module	No. connections within the module	Incidence	No. module	Seats offered in the module	Incidence
AHO	Alghero Fertilia	1	10	1.4%	1	2,835	0.3%
ALL	Albenga Airport	6	1	0.3%	7	112	0.1%
AOI	Ancona Falconara	6	2	0.6%	7	340	0.2%
AOT	Corrado Gex Airport	6	1	0.3%	7	96	0.0%
BDS	Brindisi Casale	6	5	1.4%	7	2,921	1.5%
BGY	Bergamo Orio Al Serio	1	24	3.4%	1	10,396	1.2%
BLQ	Bologna G. Marconi	6	15	4.3%	7	5,097	2.6%
BRI	Bari Palese	6	10	2.9%	7	6,283	3.2%
BZO	Bolzano	6	1	0.3%	1	94	0.0%
CAG	Cagliari Elmas	6	14	4.0%	7	4,453	2.2%
CIA	Rome Ciampino	1	23	3.2%	1	13,902	1.6%
CRV	Crotone	6	1	0.3%	7	222	0.1%
CTA	Catania Fontanarossa	6	15	4.3%	7	12,334	6.2%
FCO	Rome Fiumicino	6	32	9.2%	7	50,671	25.4%
FLR	Florence Peretola	6	8	2.3%	7	2,171	1.1%
FRL	Forlì Luigi Ridolfi	1	4	0.6%	7	1,260	0.6%
GOA	Genoa C. Colombo	6	8	2.3%	7	3,651	1.8%
LIN	Milan Linate	6	14	4.0%	7	27,416	13.8%
LMP	Lampedusa Airport	6	2	0.6%	7	363	0.2%
MXP	Milan Malpensa	6	19	5.5%	7	14,500	7.3%
NAP	Naples Capodichino	6	16	4.6%	7	10,273	5.2%
OLB	Olbia Costa Smeralda	6	10	2.9%	4	3,594	0.7%
PEG	Perugia Sant Egidio	1	1	0.1%	1	189	0.0%
PMF	Parma	1	1	0.1%	1	189	0.0%
PMO	Palermo Punta Raisi	6	16	4.6%	7	11,574	5.8%
PNL	Pantelleria Airport	6	2	0.6%	7	529	0.3%
PSA	Pisa Galilei	1	13	1.8%	1	11,304	1.3%
PSR	Pescara Liberi	6	7	2.0%	7	908	0.5%
REG	Reggio Cal. Tito Menniti	6	7	2.0%	7	1,723	0.9%
RMI	Rimini Miramare	1	2	0.3%	2	174	0.1%
SUF	Lamezia T. S Eufemia	6	9	2.6%	7	3,978	2.0%
TPS	Trapani Birgi	6	6	1.7%	7	1,018	0.5%
TRN	Turin	6	13	3.7%	7	8,700	4.4%
TRS	Trieste - Ronchi Dei Leg.	6	4	1.1%	7	1,151	0.6%
TSF	Treviso	1	14	2.0%	1	5,820	0.7%
VBS	Brescia Montichiari	1	2	0.3%	1	378	0.0%
VCE	Venice Marco Polo	6	16	4.6%	7	8,167	4.1%
VRN	Verona	6	10	2.9%	7	3,099	1.6%

Table 6. Classification of the Italian airports into the modules derived considering: i) the possible existence of connections and ii) the number of seats offered. The table also shows by means of % value the contribution of each airport to its module.

5. Conclusion

The purpose of the analyses presented in the previous paragraphs was to provide a classification of airports that could lead to the identification of their respective roles and characteristics of homogeneity. Put together, the results yield interesting views and provide at the same time indirect confirmation of the exactness of the analyses. Table 7 presents the percentage of distribution of clusters of airports among the different modules.

Module/Cluster		1) worldwide hub	2) hub	3) secondary gate	4) connect. EU low cost	5) no low-cost gate	6) regional airports	7) minor low-costs	8) local airports
1)	Heathrow/UK - Low cost	25%	25%	18%	70%	11%	18%	70%	14%
2)	Orly /France	0%	6%	18%	0%	9%	23%	4%	12%
3)	Oslo/Norway	0%	6%	0%	0%	11%	0%	0%	18%
4)	Frankfurt/Germany – Low cost	25%	19%	18%	24%	11%	9%	13%	5%
5)	Stockholm / Sweden	0%	6%	0%	0%	7%	2%	0%	12%
6)	Athens/Greece - Cyprus	0%	6%	9%	0%	7%	2%	0%	11%
7)	Fiumicino/Italy - Paris CDG	25%	6%	9%	0%	15%	18%	0%	5%
8)	Madrid/Spain	25%	0%	0%	0%	28%	0%	4%	5%
9)	Helsinki/Finland	0%	6%	0%	0%	0%	0%	4%	7%
10)	Prague/ East vs West link	0%	13%	18%	3%	0%	9%	3%	3%
11)	Porto/ Portugal	0%	0%	9%	3%	2%	5%	0%	5%
12)	Copenhagen/Denmark	0%	6%	0%	0%	0%	9%	1%	3%
13)	Reykjavik/Iceland	0%	0%	0%	0%	0%	5%	0%	2%
No. Airports / cluster		8	16	11	33	46	44	71	238

Table 7. Comparison of the groups identified through cluster analysis (columns) with the modules derived through simulated annealing (rows). The percentage shows the number of existing airports normalized to the total of the cluster they belong to.

From the joint analysis of the modules and clusters we identified, the following conclusions may de drawn:

- The majority of the modules include at least one airport (six in the case of module 1) which for its characteristics may be identifiable as global or regional hub (cluster 1 or 2). An exception is represented by the Icelandic module, which is strictly local, and the Portuguese headed by Lisbon airport, classified as secondary gate.
- The first module includes, in addition to the vast majority of the English, Dutch and Irish airport network and the London-based airports of Heathrow, Gatwick and Stansted, 70% of the European airports which were classified as low-cost connectors and minor low-cost airports.
- The typical pre-deregulation European airport network, with all domestic networks centred around the main airport and the traditional main carrier, has to date been maintained in limited areas such as northern Europe, especially in the Scandinavian peninsula, and southern Europe, namely in Greece, Spain, France, Portugal and Italy. In these modules low-cost airports may be said to be hardly present (cluster 4 and cluster 6).

- The largest European traditional carriers, such as Air France or Lufthansa, have strategically sought integration with the network of vulnerable rivals, namely Alitalia, Austrian Airlines or Swiss Airlines, with the aim to increase their feedering area and the number of connections towards their main hubs. Examples of this are the presence of Charles de Gaulle within the module headed by Fiumicino and the integration of the major Austrian and Swiss airports into the module headed by Frankfurt airport.
- Some minor airports do not belong to their domestic module and appear instead within an international network (module 1). This has been favoured by the development of the low-cost phenomenon, with its *point-to-point* connection structure bypassing the domestic *hub-and-spoke* networks, thus leading to integration at a European level.
- In those European countries where the development process of the low-cost model has seen great improvements, as is the case in Great Britain, Ireland and The Netherlands, the network created following the liberalization of the market has been integrated with the key domestic systems. This kind of module is the first in Europe showing a spatial integration of the *hub-and-spoke* and *point-to-point* models within a European network reaching beyond domestic boundaries, so much so that it may be said to be hardly possible to distinguish the one from the other. A similar process of integration is also visible, although in minor degrees, in the predominantly German network headed by Frankfurt airport (module 4), which includes some German low-cost airports such as Tegel and Hannover.
- Among the "domestic" modules, the Spanish headed by Madrid is notably characterised by the presence of two of the major worldwide hubs, namely Madrid and Barcelona airports, the absence of important secondary gates and the strong share (28%) of airports classified in cluster 5 (no low-cost gates). The strategy of growth and development of the Spanish network has therefore given priority to the two main hubs, which are directly connected with a number of regional and local airports through a wide and multi-layered *hub-and-spoke* network.
- One more point of interest is given by the presence of an "atypical" module, namely n. 10, headed by the airport of Prague and including Brussels among its major airports. Its main characteristics are a low domestic concentration (a number of airports based in the Czech Republic, Slovakia, Hungary, Switzerland, Lituania and Germany can all be found in this module) and the scarcity of low-cost airports. The role of this module is to connect airports of central and eastern Europe to the very heart of Europe, represented by the airports of Brussels and Geneva.

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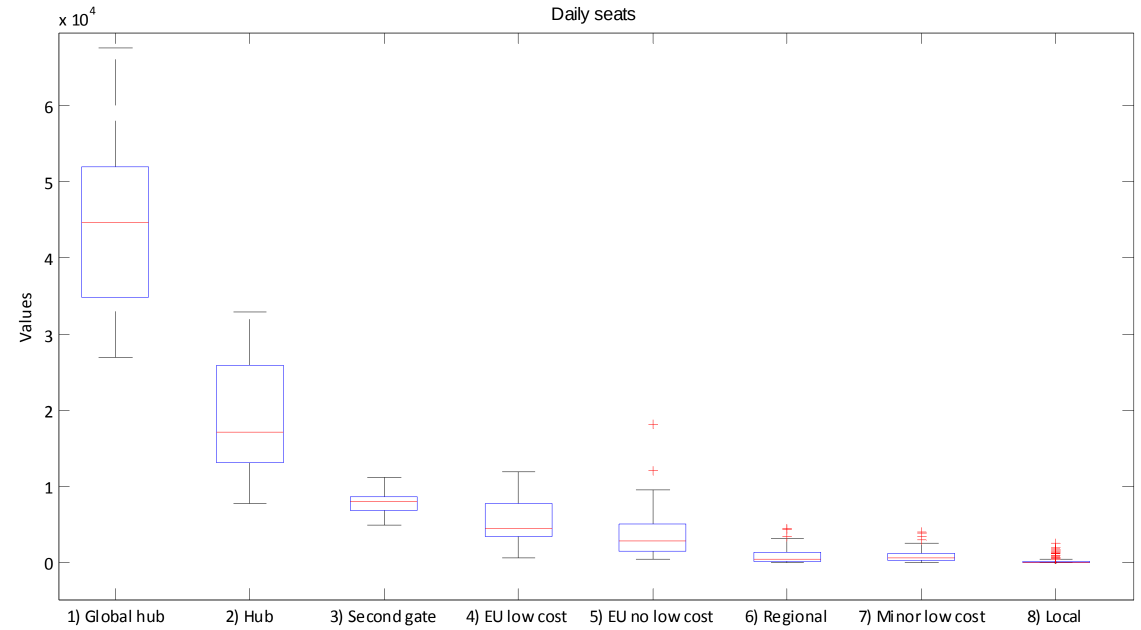
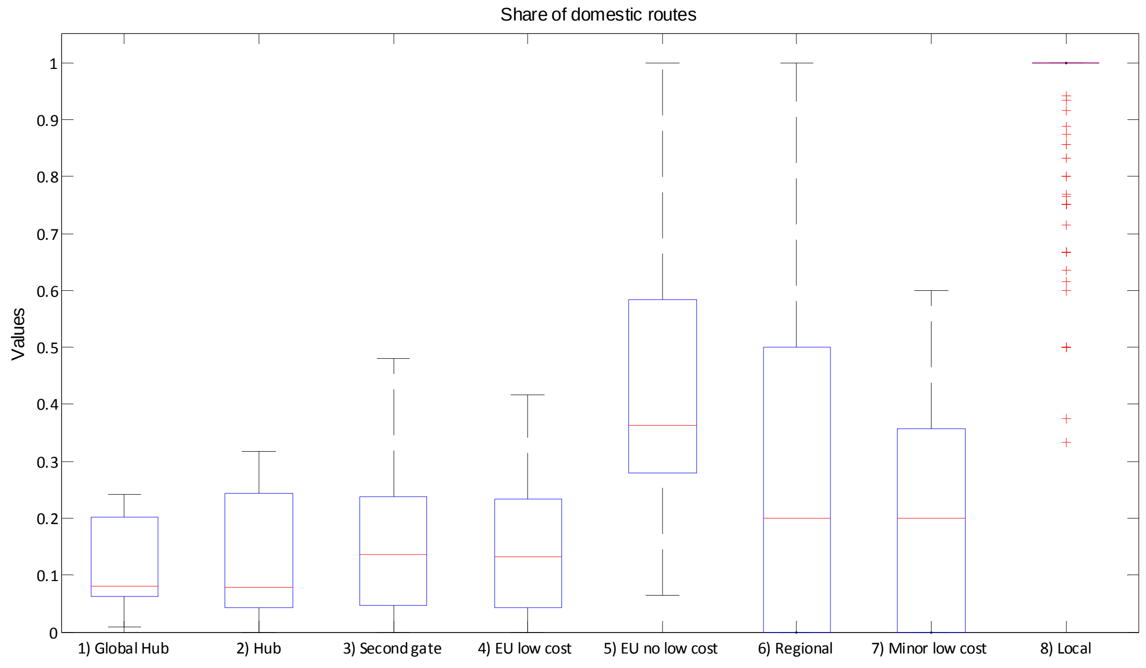
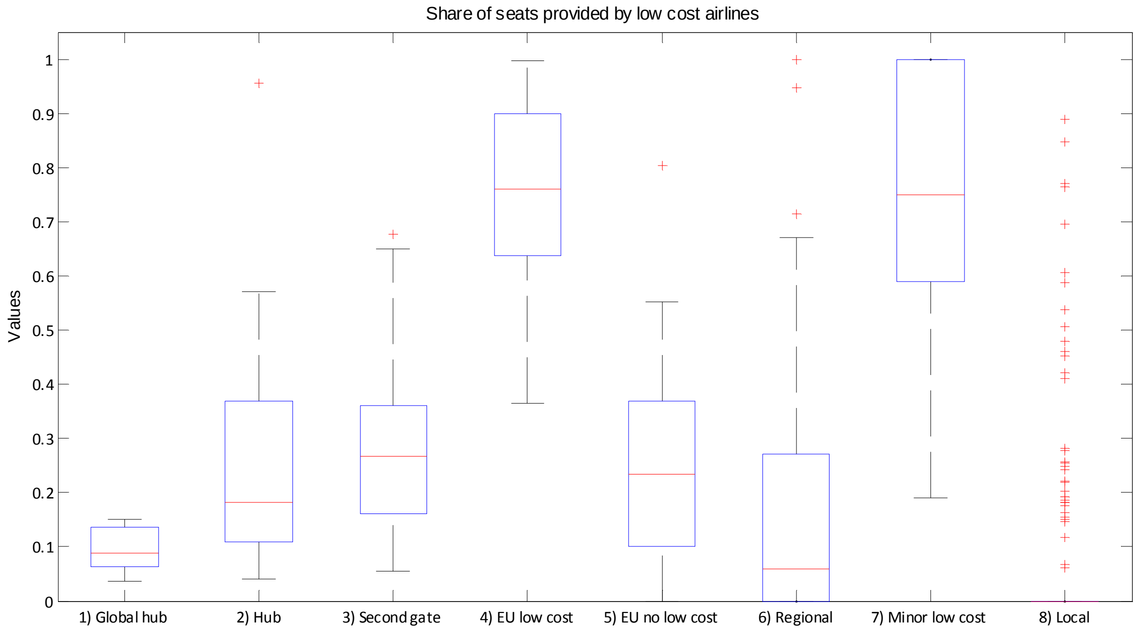
APPENDIX A – Statistics / cluster

	N° dest	Seats / day	Flights / day	% EU dest	% Dom dest	Route distr.	betweenness	Lim %	% Low cost	N° bases
cluster 1	**N° airports 8**									
Average	177.9	44,701.6	281.3	54.4%	11.8%	2.64	1,696	58%	10%	2.25
Deviation Std.	35.8	13,227.6	46.5	13.0%	8.4%	0.51	487	10%	4%	1.98
25° percentile	208.5	52,028.8	311.1	60.5%	20.0%	2.79	2,039	68%	14%	4.00
75° percentile	151.0	34,882.6	246.3	43.5%	6.0%	2.31	1,420	51%	7%	0.50
cluster 2	**N° airports 16**									
Average	116.4	19,041.7	143.3	71.1%	13.1%	2.51	1,087	67%	27%	2.38
Deviation Std.	23.0	7,685.3	36.8	13.4%	11.2%	0.53	595	20%	24%	1.09
25° percentile	135.5	25,887.6	166.5	82.0%	24.5%	3.01	1,219	86%	37%	2.50
75° percentile	98.5	13,203.9	121.3	61.5%	4.5%	2.10	693	50%	11%	2.00
cluster 3	**N° airports 11**									
Average	72.3	7,812.7	67.6	73.2%	17.0%	2.85	356	81%	30%	1.55
Deviation Std.	14.0	1,792.3	19.0	7.4%	14.9%	0.77	244	76%	21%	0.82
25° percentile	86.0	8,925.6	84.0	81.0%	26.0%	3.14	518	78%	38%	2.00
75° percentile	65.0	6,931.9	60.2	68.0%	3.0%	2.13	203	39%	15%	1.00
cluster 4	**N° airports 33**									
Average	46.5	5,523.3	41.8	91.4%	15.2%	2.15	90	63%	75%	0.33
Deviation Std.	16.8	2,899.9	21.7	7.1%	12.3%	0.57	86	16%	18%	0.54
25° percentile	58.0	7,667.3	50.9	97.0%	23.0%	2.43	107	76%	90%	1.00
75° percentile	38.0	3,504.7	26.8	87.0%	4.0%	1.77	35	50%	65%	-
cluster 5	**N° airports 46**									
Average	27.9	3,884.8	35.0	97.0%	44.6%	3.83	129	67%	25%	0.35
Deviation Std.	16.9	3,286.8	27.3	4.4%	23.6%	1.30	165	23%	17%	0.64
25° percentile	33.0	5,156.4	47.8	100.0%	58.0%	4.53	213	87%	37%	1.00
75° percentile	15.0	1,587.6	15.0	93.0%	28.0%	2.83	12	53%	10%	-
cluster 6	**N° airports 44**									
Average	13.0	1,000.4	10.7	82.6%	28.2%	1.70	18	46%	19%	0.25
Deviation Std.	12.5	1,185.8	10.8	15.2%	31.2%	0.56	30	39%	27%	0.44
25° percentile	20.5	1,437.0	17.9	97.5%	50.0%	2.00	24	84%	27%	0.50
75° percentile	3.0	161.2	2.6	74.0%	0.0%	1.25	0	0%	0%	-
cluster 7	**N° airports 71**									
Average	9.9	976.7	7.8	99.1%	21.8%	1.50	7	48%	76%	-
Deviation Std.	7.6	941.0	6.1	2.2%	18.9%	0.34	10	34%	24%	-
25° percentile	15.0	1,206.0	11.3	100.0%	36.0%	1.68	12	76%	100%	-
75° percentile	3.0	286.4	2.8	100.0%	0.0%	1.22	-	0%	59%	-
cluster 8	**N° airports 238**									
Average	3.2	233.6	3.7	100.0%	93.9%	1.38	9	40%	6%	0.09
Deviation Std.	3.0	365.7	5.1	0.0%	13.8%	0.54	19	46%	16%	0.31
25° percentile	4.0	249.7	4.6	100.0%	100.0%	1.54	9	96%	0%	-
75° percentile	1.0	48.0	1.3	100.0%	100.0%	1.00	-	0%	0%	-

APPENDIX B – Comparison between clusters






Share of seats provided by low cost airlines
Values
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1) Global hub
2) Hub
3) Second gate
4) EU low cost
5) EU no low cost
6) Regional
7) Minor low cost
8) Local