



UNIVERSITA' DEGLI STUDI DI BERGAMO
DIPARTIMENTO DI INGEGNERIA GESTIONALE
QUADERNI DEL DIPARTIMENTO[†]

Department of Economics and Technology Management

Working Paper

n. 07 – 2009

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[†] Il Dipartimento ottempera agli obblighi previsti dall'art. 1 del D.L.L. 31.8.1945, n. 660 e successive modificazioni.

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New routes and airport connectivity

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Abstract

This paper aims to provide a tool for airports to evaluate the impact of new routes on their connectivity to the network. Even if the choice to open new routes is to carriers, airports and regional governments have some tools to promote desirable connections to be offered toward specific destination. The analysis employs an innovative methodology, called simulated annealing, to verify the existence of subsystems, or modules, of high interconnectivity within the European aviation network. The single modules are intended to group together airports with very strong links between them in terms of exchanged seats, while being more weakly connected to the rest of the network. Our hypothesis is that the most desirable new routes, from the accessibility point of view, are to important airports belonging to other modules. The lower the interchange between the modules of the two airports to be connected, the higher the connectivity. To test this hypothesis we consider 467 European airports with at least one scheduled flight in autumn 2007. After classifying each airport into modules, we show that the greater improvements in accessibility, measured as the average number of steps to reach any other airport in the network, occur when new routes are offered to relevant airports of relatively unconnected modules.

Keywords: network modularity, new routes, connectivity

1 Introduction

Privatization and deregulation have strengthened the competitive behaviour of airport. This has led to a growing literature on airport benchmarking and airport performance evaluation (Graham, 2005; ATRS, 2007; Kinkaid and Tretheway, 2006; Oum and Yu, 2004). Among other variables employed to evaluate airport performance, connectivity is gaining importance. Since 2000 IATA started to explicitly evaluate the level of airport connectivity in its airport performance analysis (IATA, 2000). Recent work (Malighetti et al., 2008b) also suggested a relation between airport connectivity and efficiency.

The level of connectivity is a matter of interest also for local authorities that attempt to improve the level of service for their territories. They usually support airport connectivity by setting up routes development incentive schemes. While the respect of the non discriminatory rules (EC, 2005) has been the major concern when promoting routes development schemes, less attention has been devoted to understanding which new routes may be the most preferable in terms of connectivity gain.

The widespread of hub and spoke system and its overlapping with point to point structures has made measuring airport connectivity a challenging task. While several improvements have been made in order to better address the measure of connectivity (Burghouwt and Veldhuis, 2006; Cronrath et al., 2008; Guimerà et al., 2005; Malighetti et al., 2008a), little has been done in order to provide easy instruments and rules to airports and local governments in order to faster rank connectivity gain between two different new route options.

In this paper we suggest that identification of sub modules within the airport network can help airports to easily predict the connectivity gain of each new route. A modules identification based on simulated annealing has been applied to the European network, and a massive simulation has been conducted in order to test the connectivity gain of each new route. Several simple rules of thumb have been tested and identified. Moreover modules derived from network partition can be interpreted as strategic groups thus being a base for new ways for evaluating airport rivalry and benchmarking.

1.1 Airport connectivity

In literature on air transport there is not a precise definition of connectivity. Typically, connectivity measures allow to identify how it is easy to reach the rest of the network starting from an airport or which are the opportunities for interconnections that the airport offers

(centrality) with the latter typically employed in order to measure performance of airline hub (Bootsma, 1997; Burghouwt and de Wit 2005; Dennis 1994, Dennis 1998).

Connectivity is important for airport, airlines and local authorities. For airports, connectivity is employed to benchmark their performance against other airports (IATA 2000) to better understand on which origin - destination they can provide a competitive hub service and to evaluate self help hubbing strategies. More in general, as discussed by Burghouwt (2007) connectivity has an important role in setting strategic airport planning.

Connectivity measure can be applied to a single airlines network thus allowing a performance comparison among airlines, a rivalry analysis (Veldhuis 1997) and a better understanding of benefits coming from network consolidation as a result of alliances and partnerships. For policy makers, connectivity measures allow to monitor the level of service provided to the local area, to evaluate the cohesion to the rest of the country for example in term travel times required to reach a given share of country GDP (Malighetti et al. 2008a).

Burghouwt and Redondi (2008) analysis showed that connectivity measures differ from traditional size based measures typically employed to rank airport and to proxy their competitive position. Connectivity thus needs specific indexes. The connectivity could be represented according to the graph theory as the number of step required to reach a destination. The standard connectivity index can be weighted by service frequency or by the number of seat offered. In order to develop measure that more realistically represent the connectivity chance for passengers, several adjustments can be imposed in order to account for temporal coordination and connection quality. Thresholds can be imposed in term of maximum number of steps and minimum and maximum connecting time at intermediate airports.

For a complete review and comparison of connectivity measures see Burghouwt and Redondi (2009). Following their findings the choice of the connectivity index depends on the scope and on the complexity of the analysis. Given the strong computational efforts in recomputing the connectivity index when simulating the effects of each new route, in this paper we will employ the connectivity index based on the shortest path length (see section methodology for more detail analysis).

1.2 Network features and modules

Liberalization and the development of multi hub and spokes system have boosted the complexity of the airport network. In deregulated market likewise the ECAA (European

common aviation area), it is no longer possible to identify a simple hierarchical structure as in the past, where national hub and very few other airports was connected each other and they played the role of gateway for all the other minor airports of the country. The increasing network complexity has induced a new literature stream approaching the airport network from the perspective of the complex network theory. Indeed, Airport network's topology can be analyzed by employing graph theory. The most recent theoretical and empirical studies by Watts and Strogatz (1998), Barabási and Albert (1999), Amaral et al. (2000), and Albert and Barabási (2002) enhanced the understanding and the application of complex network theories. Empirical studies (Guimerà et al., 2005; Bagler, 2004; Li and Cai, 2004) classified airport networks as similar to "small world, scale-free networks". In small world, scale-free networks new route tend to be added toward airports with already a high degree (number of connections). Several studies (Guimerà et al., 2005; Bagler, 2004; Guida and Funaro, 2007), find that airport network real structures differ from the theoretical configuration of "small world, scale-free networks", because of the existing political barriers and of the incremental congestion costs in the dynamics of adding new routes to high connectivity airports.

In order to better understand anomalies of real networks compared to the theoretical configurations, Guimera et al. (2007) examine in deeper details the properties of sub-modules forming real complex networks and their interconnections. Guimerà et al. analysed the air transport network as well Internet and metabolic networks. They find that the properties of sub-modules forming complex networks and their interconnections have distinct patterns of connections among nodes with different roles and that structural features emerged cannot be captured by means of often studied global properties. Our approach to network partition follows Guimerà et. al. (2007) proposed methodology

1.3 Modules and strategic group

Strategic analysis traditionally recognizes that firms are not homogeneous (Hatten, and Schendel, 1977) within the same industry, rather some firms are more alike than others, and can be grouped together. The seminal theoretical background on strategic groups has been provided by Hunt (1972), Porter (1976, 1979) and Caves and Porter (1977). Strategic groups in industries can be identified based on similarities in firm scale, similarity of products and services in terms of price, features and quality; similarity in technology, or the similarity in customers served, among other dimensions. For taxonomy of the variables employed see

McGee and Thomas (1986). Strategic groups have been employed in order to explain rivalry patterns and different profitability within the same industry.

In the air transport field, studies on airlines (Peteraf, 1993) supported the Porter suggestion (Porter, 1979) that rivalry is greater across groups than within groups. In the field of airport business, little has been done with the aim to explicitly identify strategic groups and rivalry dynamics.

The airport industry is an interesting case. On one side, airports are very heterogeneous in size, profitability and role played in the network. On the other side, airports with strong differences in size and role are operated by the same airlines and serve the same group of passengers.

The formers have been traditionally considered as the main source of group identification. The Borenstein study (1989) firstly recognized influence of being a hub on pricing and profitability of the air transport as a whole.

Recent studies suggest (Gulati et al., 2000) that a firm's network of relationships is a source of both opportunities and constraints and thus a network perspective offers the potential for mapping intra-industry structure in novel ways. In the case of airports, the first source of relationship between two airports is of course the presence of a route connecting each other. It is easy to understand why the presence of a route inexorably interconnects the behaviour and the performance of the two airports (same airlines and passengers served).

Thus module identification based on the level of interconnections is a novel way to identify strategic groups in airport industry and to analyze rivalry dynamics.

2 Methodology of research

We employ an innovative technique to divide the overall European network into modules. 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:

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

where N_m is the number of modules (\leq 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).

Our aim is to provide guidelines for airports to identify the new routes that would enhance the air-side accessibility offered to departing passengers. Our research hypothesis is that the most desirable new routes, from the accessibility point of view, are to important airports belonging to other modules. In particular, the lower the interchange between the modules of the two airports to be connected, the higher the connectivity gains.

In order to test our assumptions, we will employ the measure of accessibility known as Shortest Path Length (Cronrath et al., 2008; Malighetti et al., 2008; Shaw & Ivy, 1994). The Shortest Path Length between two nodes i and j of a network (SPL_{ij}) is generically defined as the minimum number of steps necessary to connect them. In the case of air transportation networks, this index corresponds to the minimum number of non-stop flights necessary to

connect two airports. The higher the SPL_{ij} the longer the detour to connect airport i and j , in terms of number of flights. If two airports are not connected either directly or indirectly, $SPL_{i,j}$ is set to infinite.

Following Burghouwt and Redondi (2009) the accessibility index A_i from a departing airport i is defined as follows:

$$A_i = \sum_{j \in N_i} \frac{1}{SPL_{i,j}} \quad (2)$$

Where N_i represents the set of airports that can be reached from airport i . This index represents the accessibility connection in terms of the equivalent number of one-step connections. For example (see figure below) , if an airport can reach only three other airports with SPL respectively equal to 1, 2 and 2, the equivalent number of one-step connections is 2 ($1/1+1/2+1/2$) since n -step connections weigh $1/n$ of single step connections.

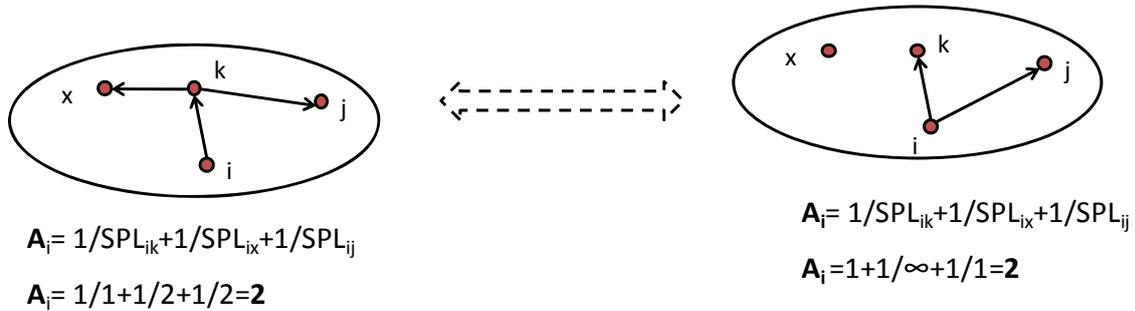


Figure 1. Example of two elementary networks with the same accessibility index A_i

3 Data

The empirical analysis refers to the European network. Data include country belonging to EU25 plus Norway, Switzerland and Iceland. We include all airports with at least one scheduled flight during autumn 2007 as reported by Innovata in its SRS databases. Overall we included 467 airports and 7254 one way routes. Figure 2 shows how the European network appeared in autumn 2007. Table 1 report airport degree (number of direct connection) and daily seats means and ranges.

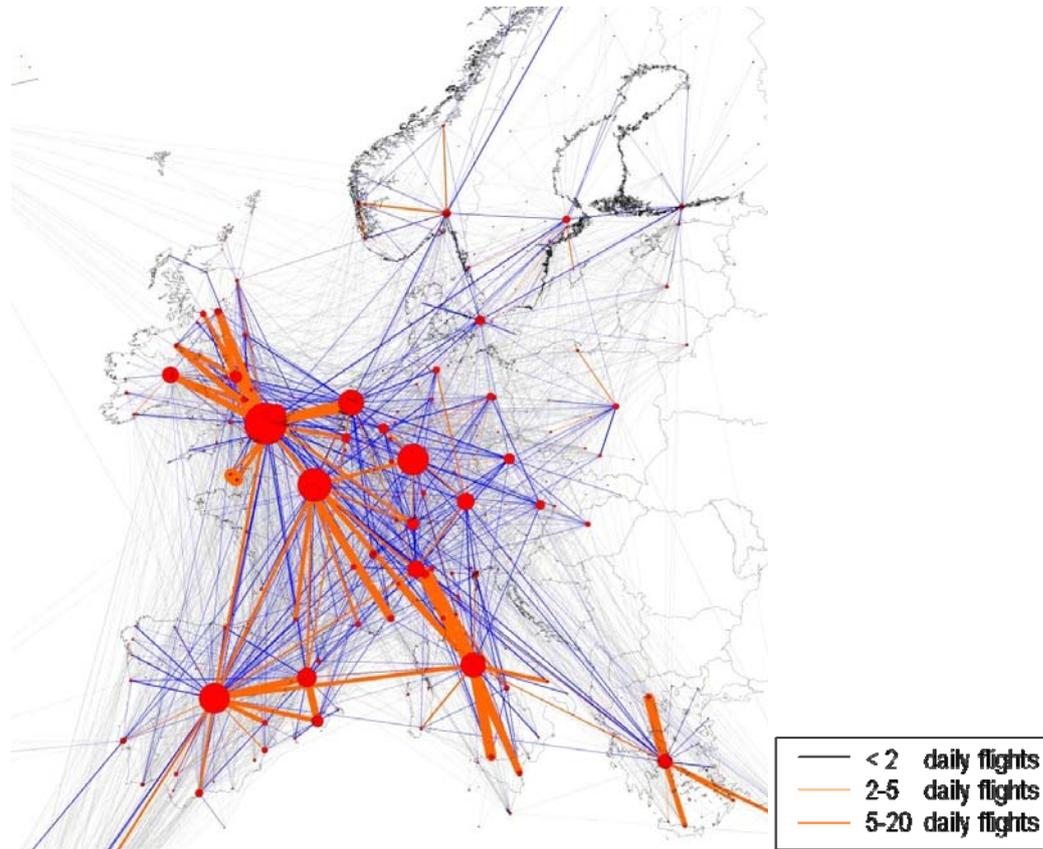


Figure 2. Airport network as of autumn scheduling 2007.

	Mean	Max	Min
Daily Seat offered on departing flights	9.094	135.227	14
Degree (n. direct connection per airport)	19,1	232	1

Table 1. Mean and ranges of airport degree and daily seats offered.

4 Empirical analysis

4.1 Simulated Annealing

This section presents result of the module identification based on the simulating annealing. Table 2 shows the modules derived by considering the number of offered seats per route into the algorithm of modularization.

More specifically, 13 modules were generated, stretching from a maximum number of 128 airports (first module) to a minimum of 7 (13th module). Major airports are those with the higher number of offered seats (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”.

The HHI (concentration index) per airport and country¹ shows whether the connections operated in a module are strongly concentrated around the airports and countries of reference.

Referring to the country HHI, it is possible to classify the modules into two categories. The first relates to modules with higher country concentration indexes. One would expect to find these modules in an un-liberalized environment since they are composed of mainly domestic airports headed by the most important airport in the country. The French, the Norwegian, the Swedish, the Greek, the Italian, the Spanish, the Finnish, the Portuguese, the Danish and Icelandic modules belong to this category.

The second kind of module comprises airports of different countries and thus lower country concentration index. Module 1,4 and 10, headed by Heathrow-Dublin, Frankfurt-Palma De Mallorca and Brussels-Prague respectively, belong to this category.

In particular, the first module 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. The European low-cost and the English and Irish traditional networks have merged. In other words, 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.

Interestingly, the “Italian” module headed by Fiumicino has Paris Charles De Gaulle as the major airport. The latter cannot be included into module 2 with the other French airports because they are better integrated with the second-largest Paris-based airport of Orly. This is partially explained by the recent development of a high-speed train service as an alternative to the airline network to connect Paris Charles De Gaulle and some of the main French cities. 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. This may be explained by the secondary role played by Alitalia within Skyteam, its worldwide

¹ 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.

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.

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 Danish module headed by Copenhagen.

No.	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-Ruzyně	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 2. Modules derived through the use of the simulated annealing method considering the seats available on the direct connections between the 467 airports examined.

The percentage of internal connections measures the “compactness” of the modules and is calculated as the number of seats available on routes within the module divided by the total number of European seats offered by the airports of the module. A part from the isolated Icelandic module, which has a 100% percentage of internal connections, the most compact modules are the Norwegian module and, surprisingly, the international module headed by Heathrow-Dublin.

Figure 3 maps the airports of the different modules. Interestingly, Module 1 also includes low-cost airports in Spain, France and Italy and the main airports in Romania

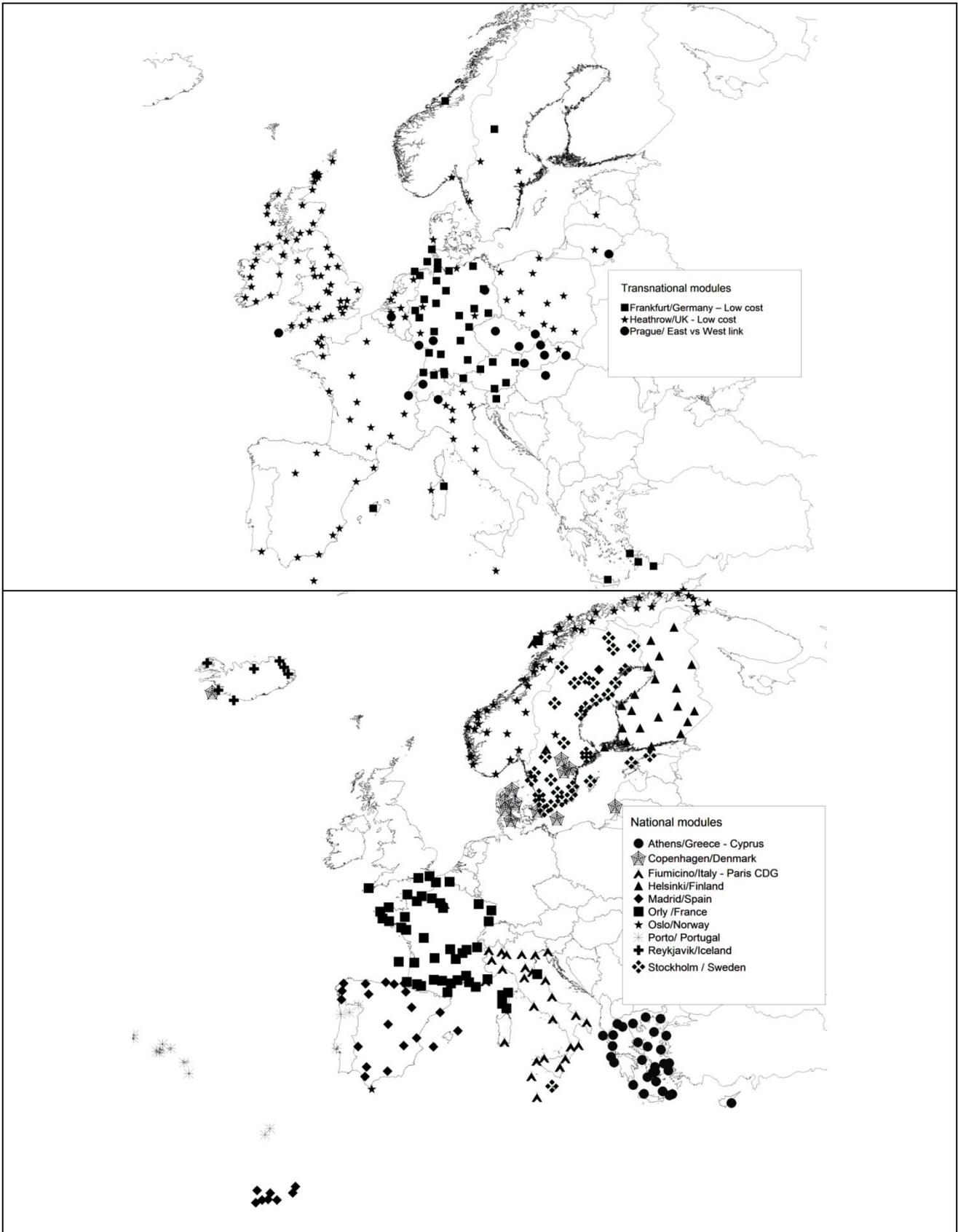


Figure 3. Maps of the modules derived from the simulated annealing. The top figure represents the airports belonging to the three transnational modules (module 1, 4 and 10) with a Country concentration index lower than 6,000. The bottom figure shows the “national” modules with a higher concentration index.

Table 3 shows the exchanges of offered seats among the modules. It is possible to see that the highest exchanges are within each module. The only exception is module 10 headed by Brussels which exchanges more seats with module 1. Even if the percentage of seats exchanged among airports in the same module is a good proxy for the compactness of the module, the modularity function, described in the methodology section, weights compactness against the dimension of the module, in terms of offered seats. In particular, the maximization of this objective function tends to form small and compact modules. This is to avoid the paradoxical solution in which all the airports and classified in the same module, which a % of internal connection which equals 100%. For the same reason the strong module headed by Heathrow and the weak module headed by Brussels are considered separately even if there the latter exchange heavily with the former.

No.	Major airport	1	2	3	4	5	6	7	8	9	10	11	12	13
1	London Heathrow	64%	3%	1%	11%	1%	1%	6%	6%	1%	4%	1%	1%	
2	Paris Orly	16%	57%	1%	6%			8%	5%		4%	2%		
3	Oslo	9%	1%	74%	3%	4%		1%	1%	1%	2%		5%	
4	Frankfurt	15%	2%		56%	1%	3%	7%	9%	1%	3%	1%	2%	
5	Stockholm-Arlanda	10%	1%	5%	7%	58%		2%	1%	5%	4%		7%	
6	Athens Eleftherios	12%			26%		49%	7%	1%		4%			
7	Paris Charles De Gaulle	17%	4%		16%	1%	2%	46%	6%		5%	2%	1%	
8	Madrid Barajas	20%	2%		18%			6%	48%		3%	2%	1%	
9	Helsinki-Vantaa	12%	1%	2%	11%	10%		3%	3%	44%	6%		6%	
10	Brussels National	29%	5%	2%	17%	3%	3%	11%	7%	2%	15%	3%	3%	
11	Lisbon	16%	4%	1%	16%			8%	12%		6%	35%	1%	
12	Copenhagen	21%		10%	17%	11%		5%	2%	4%	7%	1%	21%	
13	Reykjavik Domestic													100%

Table 3. Seat exchanges between any couple of modules.

4.2 Sensitivity analysis

The simulating annealing methodology classifies each airport in one and only one module, following the maximization of the modularity function. However, it is possible that some airports may be included in other modules with only a limited loss of the objective function. In order to assess the robustness of the classification into modules, in this section we carry out a sensibility analysis. For any airport it is possible to calculate the objective function loss derived from classifying it into any other module. The 2nd best module for each airport is the module in which the loss of the objective function is at its minimum. We calculate a relative proxy for robustness, called sensibility index defined for each airport as the objective function loss passing from the first-best to the second-best module divided by the possible maximum

loss. The latter is computed under the assumption that the airport offers seats only to airport belonging to the first-best module. In the case of the small airport with a few routes only towards other airports of the same module, the sensibility index equals 100%, since the airport has no exchange with the other modules. The lower the sensibility index, the lower the robustness of classifying an airport into its first-best module. Unsurprisingly, the sensibility index of the airports belonging to the Icelandic module is 100% since they do not exchange out of their module.

Module No.	Major airport	Number of airports	Range				
			0.8-1	0.6-0.8	0.4-0.6	0.2-0.4	0-0.2
1	London Heathrow	128	50%	16%	10%	9%	14%
2	Paris Orly	48	48%	15%	19%	8%	10%
3	Oslo	48	88%	6%	2%	0%	4%
4	Frankfurt	46	33%	17%	11%	15%	24%
5	Stockholm-Arlanda	33	67%	9%	6%	9%	9%
6	Athens Eleftherios	31	74%	0%	6%	16%	3%
7	Paris Charles De Gaulle	31	29%	16%	10%	16%	29%
8	Madrid Barajas	30	33%	17%	3%	27%	20%
9	Helsinki-Vantaa	20	75%	0%	0%	15%	10%
10	Brussels National	17	18%	6%	6%	12%	59%
11	Lisbon	16	75%	0%	0%	6%	19%
12	Copenhagen	12	42%	0%	17%	17%	25%
13	Reykjavik Domestic Airport	7	100%	0%	0%	0%	0%

Table 4. Distribution of sensibility indexes for airports in each module.

Table 4 shows the distribution of the sensibility index among airports in each module. For example, 50% of airports belonging to module 1 have a higher than 0.8 sensibility index. In the Norwegian module, 88% of airports have a higher than 0.8 sensibility index. The higher the number of airports with low sensibility index values, the looser the module. The module 10, headed by the Brussels airport has 59% of airports with a sensibility index lower than 0.2. It is the loosest module in the European network, as indicated also by its lowest compactness (see table 2).

4.1 Connectivity analysis

In this paragraph we elaborate the connectivity index of each airport calculating the A_i index as described in the methodological section. In figure 4 we report the distribution of the connectivity index and of the airport degree. Airport with higher number of direct connection

obviously tend to have higher connectivity but this is not a strictly relation. This is confirmed by the non monotonic trend of the direct connection line. Further when airport degree decreases the connectivity tend to decrease proportionally less. In other words airports with few connections can still show good connectivity index if they are direct connected to important gateway. In table 5 we report the connectivity statics by module. Module 4 leaded by Frankfurt airport show the highest average connectivity value. Also the module with low cost airports score good performances that confirm the spread of such as network in Europe.

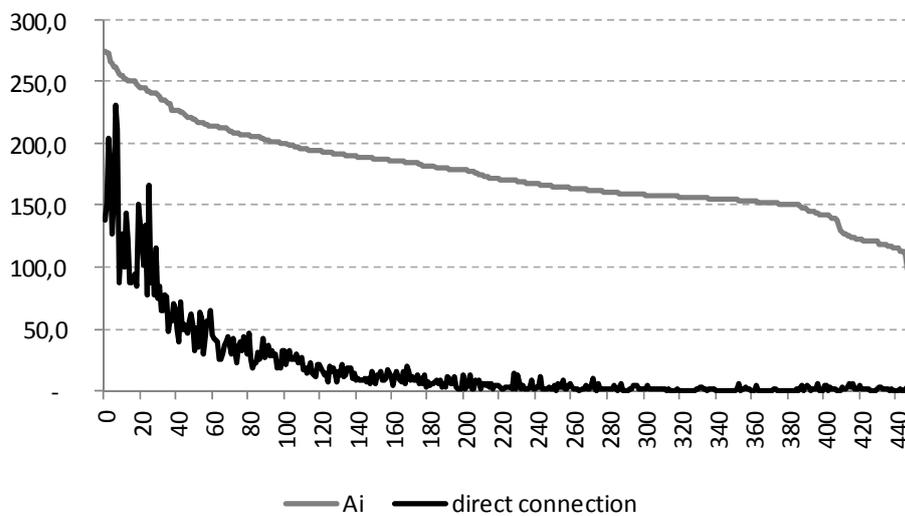


Figure 4. Airport degree (n. of direct connection) and connectivity index (Ai) distribution

Summary statistic of the connectivity index by module						
Module No.	Major airport	N. of airports	mean	max	min	St. dv
1	London Heathrow	128	187,41	275,45	116,42	32,73
2	Paris Orly	48	167,13	240,98	80,80	33,73
3	Oslo	48	151,81	257,82	98,10	30,40
4	Frankfurt	46	199,07	266,82	116,42	34,43
5	Stockholm-Arlanda	33	162,67	251,82	116,42	25,67
6	Athens Eleftherios	31	164,15	245,90	117,69	21,73
7	Paris Charles De Gaulle	31	189,33	260,28	121,80	32,00
8	Madrid Barajas	30	192,47	266,28	145,38	28,10
9	Helsinki-Vantaa	20	161,88	241,48	153,53	20,99
10	Brussels National	17	183,66	251,95	88,57	43,74
11	Lisbon	16	157,19	235,40	112,90	37,87
12	Copenhagen	12	179,57	253,48	158,17	29,85
13	Reykjavik Domestic Airport	7	3,71	5,00	3,17	0,74

Table 5. Summary statistic of the connectivity index Ai by module.

In order to test which new routes bring higher connectivity gains, we consider any possible new route in our airport network. We have 467 airports with a potential number of direct flights equal to $467^2 - 467 = 217,622$. By subtracting the number of existing direct flights, 7,254, we find 201,368 which are the number of new routes that can be added to the network.

For each of the 201,368 new routes we calculate the connectivity gain $\Delta A_{i,j}$, defined as the increase in the accessibility index for the departure airport i , A_i , as defined in the methodology section, when we add a new flight from airport i to airport j . Table 5 reports the summary statistics related to the maximum connectivity gain reached by each airport among the gain obtained by the airport adding any of the possible new routes.

The connectivity gain brought by a new route is due to two effects. Firstly, there is a direct gain due to the new connection between the connected airports i and j , since $SPL_{i,j}$ becomes 1. For example, if the new route is to an airport that could not be reached otherwise, the direct component of the connectivity gain $\Delta A_{i,j}$ is 1.

Secondly, there is an indirect effect since shortest paths from airport i to other airports k could also decrease, by employing as first step the new route to airport j .

If we do not consider indirect connectivity effect, the maximum gain adding a new route is 1 (toward an airport previously not elsewhere reachable) and a minimum is 0.5 (toward an airport previously reachable by a 2 step path). As shown in table 5, for each airport exist a new route that allows an increase of the connectivity at least equal to 3.66. It means that for each airport exist a new routes that will generate a benefit in term of indirect connectivity between 2.66 and 3.16.

Max connectivity gain	
Min	3.66
Max	78.36
Mean	16.17
Std Dev	13.69
25 th percentile	5.75
50 th percentile	12.25
75 th percentile	21.56

Table 6. Summary statistic of the maximum connectivity gain reachable for any airport.

Figure 5 plots the maximum connectivity gain of each airport as function of the current connectivity level. Airport with a current connectivity higher than 175 show similar gains, (on

average equal to 5.7) while for airport with lower current connectivity the maximum gain rapidly increase with the decrease of the current value.

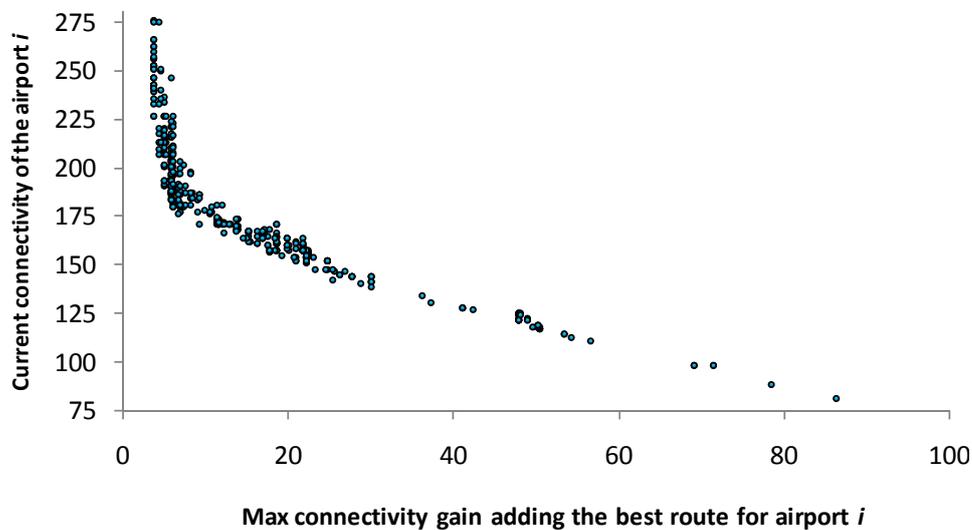


Figure 5. Current connectivity and maximum connectivity gain.

Now we want to test whether the connectivity gain depend upon the inclusion of the connected airports in different modules and on the exchange level between the two modules.

We regress the connectivity gains on the following set of independent variables:

- SizeDest is the size of airport newly connected to the departure airport i , measured as the number of offered seats;
- Interchange is the percentage of seats exchanged between the two modules to which the departure and arrival airports belong, as shown in table 3. If the departure and arrival airports belong to the same module, Interchange is set to zero.
- Dummy equals one if the two newly connected airports belong to the same module and equals 0 otherwise.

	Value	Sign
Const	1.247	0***
SizeDest	2.04E-05	0***
Interchange	-1.009	1.1E-18***
Dummy	-0.474	0***
Number of observations	201.368	

*** indicates a statistical significance (p -value) lower than 0.00

Table 7. Results of the regression analysis on connectivity gains for new routes.

The regression results are shown in table 7. It is possible to drive the following observations. The variable SizeDest is significantly positive, meaning that other, things being equal, the bigger the destination airport, the higher the connectivity gain, as one would expect. Interestingly, Interchange is significantly negative: if the two modules to which belong the departure and arrival airports are weakly connected, the increase in the accessibility index is high. Vice versa, if the departure airport opens a new route connecting to an airport in a “close” module, its connectivity gain decreases.

Finally, the dummy coefficient is significantly negative meaning that if the new route is to other airports in the same module, the connectivity gain decreases.

Looking at the coefficient in table 7 the connectivity gain obtained by opening a new route to an average-size airport belonging to an unrelated module, is 1.41^2 . It is higher than 1, due to the leverage effect offered by indirect connections. That connectivity increase reaches up to 4^3 when the new route is open to big airports belonging to unrelated module.

If the departure and arrival modules are related, the connectivity gain decrease by 0.01 for each percentage of seats interchange between the two modules. For example, if the interchange is 30%, the connectivity gain decreases by $0.3 * 1.009 = 0.3027$. If the new route is to an airport belonging to the same module, the connectivity gain decreases by 0.474.

5 Conclusion

This paper aims to provide a tool for airports to evaluate the impact of new routes on their air-side accessibility to the network. To this end, this paper employs an innovative methodology, known as simulated annealing, to classify airports into modules by considering their positions into the network.

We considered 467 European airports with at least one scheduled flight in autumn 2007. We find two different kinds of modules. The first relates to modules composed of mainly domestic airports headed by main national hub with a low presence of low-cost carriers. The

² The number 1.41 is the constant term 1.247 plus the SizeDest coefficient, $2.04E-5$ multiplied by the average number of daily-offered seats by the arrival airports, 8,165. Since the arrival airport belongs to an unrelated module, the percentage Interchange is zero.

³ In this case, the maximum number of seats offered daily is 135,227. Thus, $1.247 + 2.04E-5 * 135,227 = 4$.

second kind of module comprises airports of different countries with a predominant presence of low-cost carriers.

We measured the accessibility to the network as the average number of steps to reach any other airport in the network. We employ a simple accessibility index (see Burghouwt and Redondi (2009) for a comparison among accessibility indexes), that does not account for temporal coordination , to ease the simulation of the impact of any new routes added on network.

The results are of interest from the operators' point of view. We show that the greater improvements in accessibility occur when new routes are offered to relevant airports of relatively unconnected modules. Albeit the choice to open a new routes still need to be based also on the evaluation of the O-D demand, this tools add useful information in regard of the impact of the routes on the overall connectivity provided to the local community and could be a part of the framework employed in evaluating Air Route development schemes.

Further we believe that a classification of the airports into modules, by simplifying the network, also allows a better understanding of the competitive context in which each airport operates. For example, the groups and characteristics identified could provide a base for testing whether competition is more severe among similar airports belonging to the same group than among similar airports belonging to different groups. This study also shows that further research efforts in this direction are worth pursuing and may lead ultimately to a better understanding of airports systems as strategic groups.

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