European Transport \ Trasporti Europei (2023) Issue 93, Paper n° 2, ISSN 1825-3997

https://doi.org/10.48295/ET.2023.93.2

# The centrality of Italian airports before and after the COVID-19 period: what happened?

**Giovanni Tesoriere[1], Antonio Russo[1], Giulia De Cet[2], Chiara Vianello[2,3], Tiziana Campisi[1*]**

*[1]University of Enna Kore, Faculty of Engineering and Architecture, Cittadella Universitaria,94100, Enna, Italy*
*[2] Department of Industrial Engineering - University of Padova, 35131 Padova, Italy*
*[3]Department of Civil, Environmental and Architectural Engineering - University of Padova, 35131 Padova, Italy*

**Abstract**

Air transport in Italy accounts for around 1,8% of national production and employment. This sector has undergone a series of transformations during the recent pandemic period. The main focus of this research is the analysis of the network of national airports with more than 50.000 passengers per year both outbound and inbound and the estimation of their centrality in the presence of significant exogenous events such as the recent pandemic. The change in centrality was examined over the period 2019-2021. The methods of network analysis were applied and the results show an increased and growing centrality of some southern airports in the network, a downsizing of Rome Fiumicino airport during the pandemic period and a marginalisation in the national network of some smaller airports in the centre-north.
This first step in the research lays the foundations for better actions to promote sustainable transport planning, considering local authorities, airport managers and airlines.

*Keywords: air transport; COVID-19 pandemic; centrality; network analysis; airport*

## 1. Introduction

Transportation systems are involved in the development of the economy and society of 21st century countries. The spread of air transportation in the second half of the 20th century allowed for a significant reduction in travel time within and between countries by greatly increasing accessibility. This modal choice is crucial both when distance increases and in the presence of spatial discontinuities (Givoni & Dobruszkes,2013; Sun et al., 2017; Xia & Zhang, 2016). Hence, air transportation turns out to be the most important mode for passengers for international scale travel, and it takes on a decisive role in in-country travel when travel by rail mode exceeds 4-5 hours. This dual function implies, at times, a lack of knowledge of the role of airports in the two contexts, and thus a difficulty in proposing policies appropriate to the needs of the two macro-segments of demand: international and domestic.

[1] * Corresponding author: Tiziana Campisi (tiziana.campisi@unikore.it)

It is therefore necessary to investigate the network related to domestic traffic, to highlight criticalities related to geographical distance and the absence or presence of alternative modes of transport to cover the same route. The methodology adopted in this paper is based on centrality analysis. The airport network of the generic country can be schematized through a graph in which the nodes are the airports and the arcs are the routes; each arc is assigned a value that can refer to the structure of supply or the structure of demand. In the first case, the number of aircraft movements is considered, while in the second, the number of annual passengers on the route adds to that of annual passengers on the reverse route. The great potential offered by centrality analysis has been presented and developed in several articles (Ruhnau, 2000; Bonacich, 1987; Bonacich & Lloyd, 2001. The literature on this type of analysis is extensive and considers multiple applications. Different studies, for example, have applied centrality analysis to the network of economic exchanges in Eurasia (Iapadre & Tajoli, 2014; De Benedictis & Tajoli, 2011). Likewise, other studies have been conducted on networks with disparate characteristics (Fagiolo & Mastrorillo, 2014; Tantardini et al., 2019). Many indicators have been proposed that consider the centrality of a generic node in diverse aspects. More recent work has extended the use of network analysis to the one of social networks and the role of the centrality of different web nodes in relation to their characteristics (Haveliwala & Kamvar, 2003). In the airport field, the model called "hub and spoke" was created in the U.S. following deregulation in commercial civil aviation and it has been developing for several years. The introduction of free market rules, and the possibility of arbitrarily defining ticket prices, led to an overhaul of the architecture of air transportation, both passenger and cargo. The novelty of the research centres on the use of indicators for estimating the centrality of airport nodes. In fact, while some researches investigate indicators such as closeness, and betweenness, the present work investigates the value of centrality through the degree of centrality, the strength of centrality and the value of eigenvector, which has been little analysed by the works present in the sector literature. Future investigation steps will involve the estimation of other indicators such as closeness, betweenness and other indicators aimed at defining whether an airport node is a generator or an attractor (using disaggregated data for departures and arrivals).

## 2. Background

The crisis generated by COVID-19 has deeply affected all transportation systems: from urban ones (Campisi et al., 2022) to suburban and regional, national and international ones (Basbas et al., 2021). By (https://www.icao.int/Pages/default.aspx), the impact of COVID-19 on global scheduled passenger traffic for the year 2020 compared to 2019 levels showed:

- an overall reduction of 50% of seats offered by airlines,
- an overall reduction of 2,703 million passengers (-60%),
- a loss of approximately $372 billion in gross airline passenger operating revenue.

The impact of COVID-19 on global scheduled passenger traffic for the year 2021 (preliminary estimates), compared to 2019 levels:

- 1.5 million passengers (preliminary estimates), compared to 2019 levels:
- 40% overall reduction in seats offered by airlines,
- an overall reduction of 2.201 million passengers (-49%),

- a loss of approximately $324 billion in airline gross passenger operating revenue Eurocontrol's Comprehensive Aviation Assessment (https://www.eurocontrol.int/covid19) outlined the trend in Figure 1, which provides an accurate snapshot of the latest network picture compared to the pre-COVID-19 period.

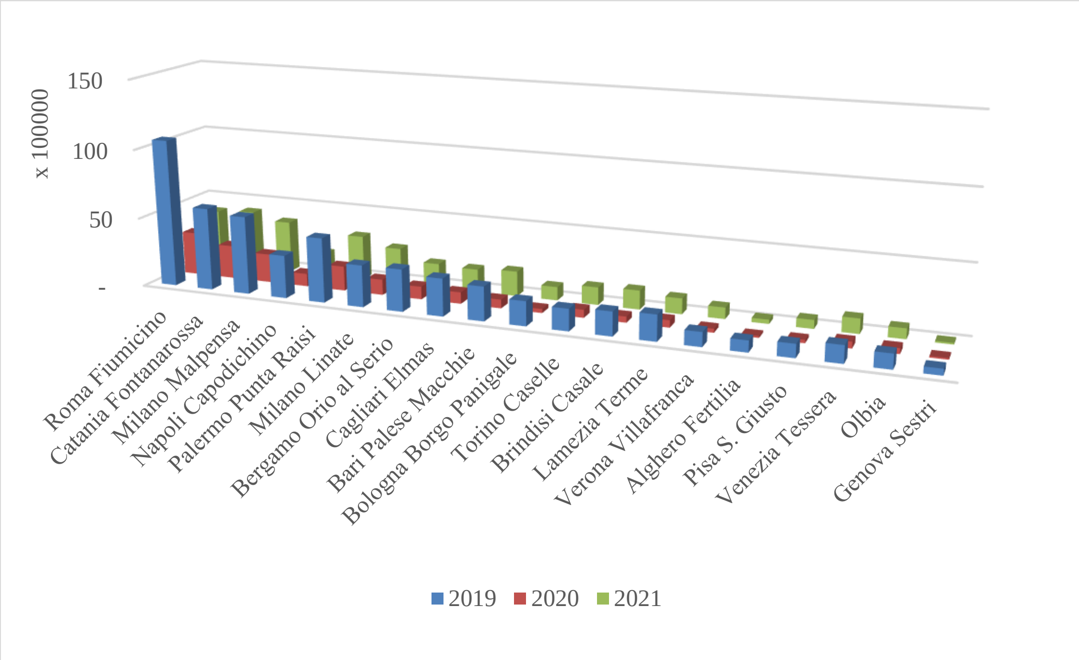


Figure 1: Arrivals+ Departures trends at major Italian airports with more than 50,000 passengers per year (period 2019-2021)

Source: https://www.eurocontrol.int/covid19

These major upheavals brought about by the COVID-19 crisis have fundamentally altered the roles of airports for domestic traffic, reshaping priorities and importance. The great wave of 2020 and 2021 has altered the centrality of airports. Some airports, past the great crisis, are almost back to pre-COVID-19 conditions. Other airports were affected by such strong changes that new centralities and trends have been determined.

The centrality analysis, with the different indicators, makes it possible to stress the evolutions and new arrangements from 2019 (pre-COVID-19) to 2020 and also to 2021.

A study conducted by (Arora et al., 2021) pointed out that the youth population is eager to return to planes after the COVID-19 pandemic. Overall, however, a significant number of people of all ages plan to fly less often in the future. Factors influencing the choice of transportation are price, speed and CO2 emissions. This comparison highlights the importance of assumptions and the need for broad consideration of all factors affecting Switzerland's future mobility system.

The pandemic, and in particular the measures taken by the government to address it, have radically transformed mobility since the onset of the pandemic. Temporary closures, orders to work from home, and other restrictions have reflected the government's goal of significantly reducing daily commuting and shifting transportation to private vehicles, at least for short trips. Long-distance travel, especially air travel, has been hit hard by restrictions imposed not only by Switzerland but also by other countries.

The aviation industry has faced epidemics and extreme events before, although not to the same extent as the recent one of COVID-19.

Recent work by (Tuchen et al. 2020) emphasized the dominant focus, in practice and research, on customer experience and service quality, as opposed to user experience. The aim was to help airports gain a competitive advantage in an increasingly commoditised industry. That study also provided an overview of the effects of the pandemic and classified the observed response mechanisms and consequently proposed a strategy for air traffic management.

Based on multiple sources of data for passengers, cargo and flight schedules, the impact of COVID-19 on the global aviation industry was assessed and data from some major airports were compared with other airports to effectively address future disruptions.

As global aviation is facing its recovery, guidelines about operational decisions were disseminated by bodies such as the International Civil Aviation Organization (ICAO), for instance terminal closures, increased cleaning frequencies, and a mandatory wearing of masks.

ICAO as well as the aforementioned research therefore emphasise the need to incorporate a resilient view of outbreaks into the future planning, design and preparedness strategies of airports and airlines.

Furthermore, ICAO emphasises that the current civil aviation system needs a coordinated global response mechanism to combat future epidemics and proposes a framework with a threat response matrix to keep aviation safe and operational during future pandemics and mitigate socio-economic fallout.

As borders closed, national governments discouraged non-essential travel and passenger demand disappeared. At the same time, European airlines were forced to react quickly to the crisis and imposed unprecedented cost-saving measures to protect their business.

A other study conducted by (Budd et al., 2020) examined how major European airlines reacted to the height of the crisis during the COVID-19 pandemic in the March-May 2020 period using data from Eurocontrol, the European network manager. The research identifies the responses that individual airline operators and parent companies have taken to contract and consolidate their operations. The results showed that changes to flight operations, fleet rationalization, staff reductions and airline reconfiguration were the most common responses.

In recent months, the resumption of a new daily normal has led airports to face some massive flight delays, operational disruptions and shortages of qualified personnel in their post-pandemic operations.

Research by (Kzda et al., 2022) also described the issues of airports during the recovery phase and focused on the specific problems airports are facing due to the lack of qualified personnel in the post-pandemic recovery period. Critical areas where airports are falling short are ground handling services and safety and security screening for passengers.

Therefore, the pandemic has not only generated heavy impacts on mobility but also produced or exacerbated a number of critical issues related to such work sector.

The present article aims to answer two main research questions:
i) What methodological approach allows studying the characteristics of nodes in a transportation network and highlighting the roles and significance of different nodes when an exogenous event, natural or anthropogenic, of great effect intervenes?
ii) Can the proposed method be directly applied to a particularly important spatial case study in the global landscape?

This research is structured as follows:

- the third paragraph describes the methodology adopted and presents the indicators with their mathematical formulation;
- the fourth paragraph defines the case study and relative data set, highlighting the results and developments related to COVID-19;
- in the end, there are final discussions and conclusions.

The manuscript is of particular interest to airport managers and airlines, but it is also of great importance to administrators at the regional and local level, in order to properly investigate large-scale mobility choices. The present article is also significant for setting national-level policies in relation to different transportation segments. This contribution aims to be useful for researchers in the field because it puts network analysis back into the field with synthetic tools to investigate the roles of six individual nodes. The methodological approach can be extended to other fields such as those defined by nodes in a social network.

## 3. Methodology

In this paper, different centrality models used in air transportation are compared. Methodologies related to network analysis and in general to the determination of the characteristics of a network have been covered in the literature (Burghouwt & Redondi, 2013; Arvis & Shepherd , 2011).

Cases where a network is subjected to a particularly impactful exogenous event, which affects most of the nodes in the network, are not present in the literature. The event may be anthropogenic (e.g., twin towers, ...) or natural (pandemic, volcanic sands, ...) with effects of different durations over time.

The network studied is the aviation network and the event is the natural one determined by COVID-19. The focus is on the role of major airports and their evolutions from pre-COVID-19 to the period of maximum COVID-19 and full lockdown to that, still COVID-19, but of lesser impact. In this sense, as mentioned in the introduction, attention is given to airports with highly frequented routes.

The employment of centrality poses a methodological problem with one indicator because only specific aspects related to that indicator are highlighted. Therefore, it is necessary to compare multiple indicators of centrality and contrast the results based on each indicator.

A first approach to define centrality can be based on the number of connections per node. This approach brings the issue of centrality back to the definition of the supply of services on the network.

A second approach is to consider the flows using each of the connections at each node. In this way one can consider not only the number of connections per node, but also the frequency of the various connections.

These indicators provide crucial results related to each node and are therefore particularly relevant. However, this method does not allow us to analyse the overall structure of the network by highlighting the centrality of a node in relation to the centralities of its connected nodes. The first indicator stresses the importance of the node as a hub of supply to other destinations, but taken to extremes, all connections could be with zero flow. The second indicator highlights the relevance of the node as a hub of demand, but again taking this to extremes, all flow could be concentrated on a single pair of nodes on which an important shuttle service might be operating. In both cases, no indications would emerge about the overall structure of the network with respect to services and with respect to demand.

Based on the considerations briefly mentioned earlier, a more advanced approach is to consider as an indicator of centrality with respect to services, the number of connections, where, however, each connection is related to the total connections of the connected node.

This approach can be developed through the theory of eigenvectors.

The different approaches are briefly recalled here.

According to (Cascetta, 2001), it is possible to define a transport network as a graph G=G (N, E) described by a set of nodes N and a set of arcs E.

The generic pair i,j represents the possible arc having the generic nodes i and j as ends.

It is also possible to define the adjacency matrix like:

$A=[a_{ij}]$.

where

$a_{ij}=1$ if nodes i and j are connected by an arc

$a_{ij}=0$ if nodes i and j are not connected

The value $w_{ij}$ is the weight of arc ij.

Therefore, the role of airports within the network was examined in this first research step, by paying particular attention to the correlation of individual nodes with transport supply and demand.

Attention was also paid to the effect produced by an exogenous event of an anthropogenic or natural nature, such as a pandemic. To study this, the centrality trends of each node were estimated for three specific periods, i.e. before, during and after the pandemic event. With regard to the analysis of centrality, three different parameters were examined, namely:

- Degree centrality, in which the centrality of the node is assessed by the number of its connections. It is an indicator that defines, for a generic node i, the number of its connected nodes in the network. Total degree centrality is defined by equation (1)

  $c_i=n_i/(n_i-1)$; (1)

  The maximum value is 1, in case node i is directly connected with all other n-1 nodes in the network. It is primarily a topological indicator and refers to the existence of connections, but it is independent of both the quantities of connections for each connected node j and their utilization.
- Strength centrality, in which, in a weighted graph, the centrality of the node is evaluated from the weight of the arcs incident on it. It is an advanced version of the previous quantity in which the weights of each connection are considered. Strength centrality is defined as equation (2)

  $s_i= \sum_j w_{ij}$ (2)

This indicator makes it possible to consider the weights of the arcs insisting on node i. This considers not only the number of connections, but for each connection the characteristic $w_{ij}$ of $arc_{ij}$. The characteristic can address either centrality with respect to passenger demand or centrality with respect to service supply.

The previous centrality indicators take into account the node's positioning within the network in terms of number of connections and weight of connections.

- Eigenvector centrality allows for an assessment that involves not only the two parameters related to generic node i, but also the characteristics, links and weight, of nodes j with which node i is connected. In this way, the centrality of the node is also evaluated in relation to the centrality of the connected nodes.

It was possible to determine the value of r, and v that satisfy the relationship:

$$Av=r\,v \quad (3)$$

where

A is the adjacency matrix defined above

v is the eigenvector related to the eigenvalue r.

In accordance with (Perron, 1907), the properties of the matrix A state that

- a real-square matrix with positive elements has a single largest real eigenvalue
- the corresponding eigenvector can be chosen to have strictly positive components.

Each element $v_i$ of the real vector v >0 expresses the centrality measure of the eigenvalue of node i.

## 4. Results

This research considers the national context of Italy, which is characterised by significant elements within air transport. Italy's geographical and socio-economic asymmetries are reflected in the airport network. The presence of geographically distant areas in the Italian network and the presence or absence of alternative modes of transport has been studied in the literature (Benedetti et al., 2012; Laurino et al., 2019). The airport system is a driver for the economic development of an area (Tveter, 2017; Cooper & Smith, 2005; Hakfoort et al., 2001; York Aviation, 2004), and allows for improved accessibility in areas lagging behind in development, even if only with the presence of secondary airports (Dziedzic & Warnock-Smith, 2016; Redondi et al., 2013). It has been seen in the literature how the spread of low-cost airlines has led to greater traffic at southern airports (Donzelli, 2010; Lupi, 2007; Laurino et al. , 2014).

### *4.1 Demand-driven network definition*

In light of the asymmetries of the country, it is essential to study the role and centrality of the different nodes in the Italian airport network in the period 2019-2021. The final objective of the work is to verify whether there have been any changes induced by COVID-19 in terms of the centrality of the nodes in the network, in relation to the different criteria and thus the related indicators, providing a quantitative assessment.

The years considered are particularly significant because, as mentioned earlier, they include: 2019 (pre-pandemic), 2020 (national lock-down period), 2021 (first year post lock-down). In each of the three years considered, the network examined is composed of airports i and j with at least one domestic route ij, where both ij and ji have at least 50,000 passengers per year. In this way, the core network consists of those routes where both outbound and inbound have at least 50.000 passengers/year. The limit indicated achieves three important effects, namely:

- it allows only those routes that are numerically significant in terms of passengers to be evaluated;
- it makes it possible to directly exploit the data available from ENAC, which exceeds 50,000 per route o/d for the three years considered;
- it enables the exclusion the effects of the intervention of public institutions within the airport network, removing routes that often exist as a result of financial interventions by the public authority, returning a network more similar to the representation of the market.

The last element recalled mitigates the effects induced by the Public Service Obligations (PSO) imposed at European level for certain air routes. The literature reveals how public authority intervention in favour of minor airports can determine even substantial changes in the network (Grimme et al., 2018; Pilar Socorro & Betancor, 2020).

The evolution of the analysed network structure for the three years (2019-2020-2021) is shown in Figure 1 (a-b-c).

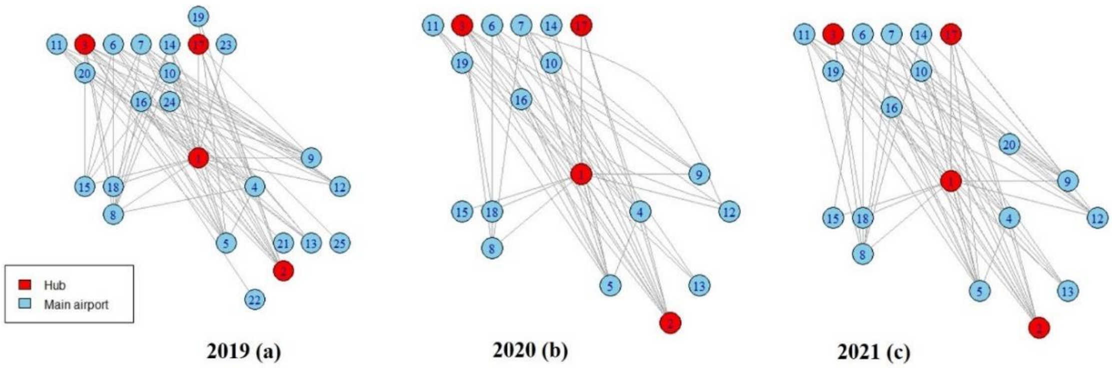


Figure 2: Overview of the airport network with more than 50,000 passengers per year in Italy

Source: Air traffic data , https://www.enac.gov.it/aeroporti/infrastrutture-aeroportuali/dati-di-traffico

The airport hubs and main nodes in the figure above are defined in Table 1.

Table 1: Identification of hubs and major airport nodes in the investigated period (2019-2021)

| *ID .* | *2019* | *2020* | *2021* |
|---|---|---|---|
| 1 | Roma Fiumicino | Roma Fiumicino | Roma Fiumicino |
| 2 | Catania Fontanarossa | Catania Fontanarossa | Catania Fontanarossa |
| 3 | Milano Malpensa | Milano Malpensa | Milano Malpensa |
| 4 | Napoli Capodichino | Napoli Capodichino | Napoli Capodichino |
| 5 | Palermo Punta Raisi | Palermo Punta Raisi | Palermo Punta Raisi |
| 6 | Milano Linate | Milano Linate | Milano Linate |
| 7 | Bergamo Orio al Serio | Bergamo Orio al Serio | Bergamo Orio al Serio |
| 8 | Cagliari Elmas | Cagliari Elmas | Cagliari Elmas |
| 9 | Bari Palese Macchie | Bari Palese Macchie | Bari Palese Macchie |
| 10 | Bologna Borgo Panigale | Bologna Borgo Panigale | Bologna Borgo Panigale |
| 11 | Torino Caselle | Torino Caselle | Torino Caselle |
| 12 | Brindisi Casale | Brindisi Casale | Brindisi Casale |

| | | | |
|---|---|---|---|
| 13 | Lamezia Terme | Lamezia Terme | Lamezia Terme |
| 14 | Verona Villafranca | Verona Villafranca | Verona Villafranca |
| 15 | Alghero Fertilia | Alghero Fertilia | Alghero Fertilia |
| 16 | Pisa S. Giusto | Pisa S. Giusto | Pisa S. Giusto |
| 17 | Venezia Tessera | Venezia Tessera | Venezia Tessera |
| 18 | Olbia | Olbia | Olbia |
| 19 | Treviso S. Angelo | Genova Sestri | Genova Sestri |
| 20 | Genova Sestri | | Pescara |
| 21 | Reggio Calabria | | |
| 22 | Comiso | | |
| 23 | Trieste Ronchi dei Legionari | | |
| 24 | Firenze Peretola | | |
| 25 | Crotone | | |

Source: Air traffic data , https://www.enac.gov.it/aeroporti/infrastrutture-aeroportuali/dati-di-traffico

*4.2 Network definition based on national and international classification*

The characteristics of the abovementioned airports can also be analysed by considering the Navigation Code and at the same time the regulations of Presidential Decree no. 201/2015 and the European classification of TEN-T networks.

Decree 201/2015 identifies airports and airport systems of national interest as essential nodes for the exercise of the State's exclusive competencies. Ten traffic basins and 12 airports of national strategic interest have been identified, at least one for each traffic basin. The national network has a total of 38 airports of national interest; 3 of them being intercontinental hubs.

The European policy for the development of TEN-T networks currently identifies an enlarged network of infrastructures to be completed by 2050 (Comprehensive network or Global network) and a narrow network consisting of the infrastructures with the highest strategic value to be completed by 2030 (Core network or Core network). Italy is involved in four of the nine Core Network Corridors (CNC): Scandinavian-Mediterranean; Baltic-Adriatic; Mediterranean and Rhine-Alps.

The characteristics of the Italian network, according to the two classifications, are shown in Table 2. Table 2: Main details of analysed airport

| *Airport* | *Regional Demand* | *National Classification* | *TEN-T Classification* |
|---|---|---|---|
| Roma Fiumicino | Centro | S | Core |
| Catania Fontanarossa | Sicilia Orientale | S | Comprehensive |
| Milano Malpensa | Nord-Ovest | S | Core |
| Napoli Capodichino | Campania | S | Core |
| Palermo Punta Raisi | Sicilia Occidentale | S | Core |
| Milano Linate | Nord-Ovest | O | Core |
| Bergamo Orio al Serio | Nord-Ovest | O | Core |
| Cagliari Elmas | Sardegna | S | Core |
| Bari Palese Macchie | Mediterraneo Adriatico | S | Comprehensive |

| | | | |
|---|---|---|---|
| Bologna Borgo Panigale | Centro-Nord | S | Core |
| Torino Caselle | Nord-Ovest | S | Core |
| Brindisi Casale | Mediterraneo Adriatico | O | Comprehensive |
| Lamezia Terme | Calabria | S | Comprehensive |
| Verona Villafranca | Nord-Est | O | Comprehensive |
| Alghero Fertilia | Sardegna | O | Comprehensive |
| Pisa S. Giusto | Centro-Nord | S | Comprehensive |
| Venezia Tessera | Nord-Est | S | Core |
| Olbia | Sardegna | O | Comprehensive |
| Genova Sestri | Nord-Ovest | O | Core |

S=strategic; O=other airport with national interest

Source: ENAC https://www.enac.gov.it/aeroporti/infrastrutture-aeroportuali/aeroporti-in-italia)

The airport basin with the greatest number of passengers is located in the North-West and characterised by the presence of the three airports in the Milan area (Malpensa, Linate and Orio al Serio) as well as the two airports in Turin and Genoa.
Next is the basin of the Sardinia region where there are three airports.
The latter is followed, with two airports each, by the Mediterranean-Adriatic, Centre-North and North-East basins.
The Central basin is characterised exclusively by the airport of Rome Fiumicino. Similar conditions apply to the remaining basins, all presenting an airport that tends to centralise most of the area's passenger traffic: Campania (Naples Capodichino), Calabria (Lamezia Terme), Eastern Sicily (Catania Fontanarossa) and Western Sicily (Palermo Punta Raisi). Of these airports, 12 are identified as strategic airports at national level. On the TEN-T network level, on the other hand, 11 are airports in the Core network, while 8 are in the Comprehensive network.
In addition, Rome Fiumicino, Milan Malpensa and Venice Tessera are identified as international hubs. Interestingly, 4 airports (respectively Catania Fontanarossa, Bari Palese Macchie, Pisa S. Giusto and Lamezia Terme) play a strategic role at national level but are part of the European Comprehensive network. In addition, the airports Milan Linate, Bergamo Orio al Serio and Genoa Sestri are part of the European Core network but are considered of non-strategic national interest.

### *3.3 Results*

Based on the formalisations proposed in the previous chapter, considering the period 2019-2023, the following values were calculated and reported in comparative tables: degree centrality ci, force centrality si and centrality of eigenvector vi.

#### *3.3.1 Degree centrality*

The total degree centrality value is higher for Rome Fiumicino for the three years analysed, with respectively 19 connections in 2019, 13 in 2020 and 12 in 2021.
The table 2 below shows the characteristics relative to the national and international classifications and the values obtained for degree centrality. A gradual decrease in degree centrality is identified for the Rome airport, due to the decline in air traffic in the pandemic years, which led many routes with the capital to values below 50k

passengers/year. It is also necessary to emphasise that the presence of a valid railway alternative, given by the high speed train, makes it possible to completely cover some connections, such as Rome-Bologna, as an alternative to the aeroplane.

Table 3: Estimated degree centrality for the analysed airports in the period 2019-2021

| Airport | National Classification | TEN-T Classification | $c_i$ 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Roma Fiumicino | S | Core | 0,792 | 0,722 | 0,632 |
| Catania Fontanarossa | S | Comprehensive | 0,458 | 0,556 | 0,526 |
| Milano Malpensa | S | Core | 0,458 | 0,500 | 0,421 |
| Napoli Capodichino | S | Core | 0,458 | 0,389 | 0,368 |
| Palermo Punta Raisi | S | Core | 0,417 | 0,500 | 0,526 |
| Milano Linate | O | Core | 0,375 | 0,389 | 0,526 |
| Bergamo Orio al Serio | O | Core | 0,375 | 0,389 | 0,421 |
| Cagliari Elmas | S | Core | 0,333 | 0,222 | 0,368 |
| Bari Palese Macchie | S | Comprehensive | 0,333 | 0,222 | 0,421 |
| Bologna Borgo Panigale | S | Core | 0,333 | 0,111 | 0,211 |
| Torino Caselle | S | Core | 0,250 | 0,222 | 0,368 |
| Brindisi Casale | O | Comprehensive | 0,250 | 0,167 | 0,368 |
| Lamezia Terme | S | Comprehensive | 0,208 | 0,167 | 0,263 |
| Verona Villafranca | O | Comprehensive | 0,208 | 0,111 | 0,263 |
| Alghero Fertilia | O | Comprehensive | 0,208 | 0,056 | 0,105 |
| Pisa S. Giusto | S | Comprehensive | 0,208 | 0,111 | 0,211 |
| Venezia Tessera | S | Core | 0,167 | 0,167 | 0,316 |
| Olbia | O | Comprehensive | 0,167 | 0,167 | 0,211 |
| Genova Sestri | O | Core | 0,083 | 0,056 | 0,053 |

Significant values are highlighted for Catania and Palermo, which gain centrality in the pandemic years.
The growth of the Sicilian airports during the pandemic period is probably related to the lack of a valid railway alternative and to the nature of the two main airports on the island to guarantee territorial continuity with the continent.
For the same reason, airports such as Genoa, Venice and Bologna were marginal during these three years: this was partly due to the airports' international profile and partly to the presence of viable modal alternatives, as well as to their geographical proximity to several other more attractive destinations.

### *3.3.2 Strength centrality*

The 'weighted centrality' indicators are calculated by taking the flows in and out of airports as weights. The flows reveals a general decline in passenger traffic due to COVID-19 restrictions in 2020.

Table 4: Estimated strength centrality for the analysed airports in the period 2019-2021

| *Airport* | *National Classification* | *TEN-T Classification* | $s_i$ | | |
|---|---|---|---|---|---|
| | | | *2019* | *2020* | *2021* |
| Roma Fiumicino | S | Core | 10.619,92 | 3096,277 | 4016,632 |
| Catania Fontanarossa | S | Comprehensive | 5923,157 | 2407,593 | 4212,805 |
| Milano Malpensa | S | Core | 5604,547 | 2070,983 | 3706,853 |
| Napoli Capodichino | S | Core | 3084,682 | 918,389 | 1644,176 |
| Palermo Punta Raisi | S | Core | 4632,075 | 1768,823 | 3184,794 |
| Milano Linate | O | Core | 2993,453 | 1112,843 | 2561,781 |
| Bergamo Orio al Serio | O | Core | 3015,165 | 914,961 | 1729,629 |
| Cagliari Elmas | S | Core | 2683,686 | 826,624 | 1622,29 |
| Bari Palese Macchie | S | Comprehensive | 2444,844 | 627,856 | 1781,136 |
| Bologna Borgo Panigale | S | Core | 1754,689 | 287,436 | 968,12 |
| Torino Caselle | S | Core | 1564,508 | 569,312 | 1264,586 |
| Brindisi Casale | O | Comprehensive | 1716,347 | 429,893 | 1358,586 |
| Lamezia Terme | S | Comprehensive | 1851,344 | 518,424 | 1124,566 |
| Verona Villafranca | O | Comprehensive | 1021,8 | 275,974 | 811,067 |
| Alghero Fertilia | O | Comprehensive | 815,165 | 131,701 | 296,935 |
| Pisa S. Giusto | S | Comprehensive | 955,801 | 227,837 | 622,92 |
| Venezia Tessera | S | Core | 1235,552 | 466,584 | 1068,678 |
| Olbia | O | Comprehensive | 1051,121 | 393,283 | 742,015 |
| Genova Sestri | O | Core | 450,912 | 104,651 | 111,428 |

Note how the downward trend from 20219 to 2020 is less marked for the island's airports: Catania has maintained values above 2.4 million and Palermo values above 1.5 million. Only five airports recorded values above 1 million: Malpensa, Linate and Fiumicino, in addition to Catania and Palermo. In 2021, all airports increased their flows and as many as 13 airports were above one million passengers. Note how, for the network considered, Catania Fontanarossa surpasses Rome Fiumicino, assuming a primary role in terms of centrality in the network.

### *3.2.3 Eigenvector centrality*

The value of eigenvector centrality considers not only the positioning of the node but also the positioning of the nodes with which the generic node is connected. In short, the score also depends on the centrality of the connected nodes. This is particularly relevant for airport traffic, as it provides a measure of the presence of connections and stopovers. The values, in general, maintain a similar pattern to previous cases.

Table 5: Estimated Eigenvector centrality for the analysed airports in the period 2019-2021

| *Airport* | *National Classification* | *TEN-T Classification* | $v_i$ | | |
|---|---|---|---|---|---|
| | | | *2019* | *2020* | *2021* |
| Roma Fiumicino | S | Core | 0,744041 | 0,645869 | 0,613714 |
| Catania Fontanarossa | S | Comprehensive | 0,52522 | 0,550582 | 0,555484 |
| Milano Malpensa | S | Core | 0,516252 | 0,54195 | 0,454686 |
| Napoli Capodichino | S | Core | 0,537078 | 0,468217 | 0,453053 |
| Palermo Punta Raisi | S | Core | 0,494204 | 0,511694 | 0,555484 |
| Milano Linate | O | Core | 0,474941 | 0,467552 | 0,557091 |
| Bergamo Orio al Serio | O | Core | 0,398121 | 0,404564 | 0,428216 |
| Cagliari Elmas | S | Core | 0,4304 | 0,314844 | 0,406595 |
| Bari Palese Macchie | S | Comprehensive | 0,405678 | 0,314844 | 0,461309 |
| Bologna Borgo Panigale | S | Core | 0,417046 | 0,16236 | 0,261902 |
| Torino Caselle | S | Core | 0,354523 | 0,332639 | 0,449635 |
| Brindisi Casale | O | Comprehensive | 0,332682 | 0,243382 | 0,395781 |
| Lamezia Terme | S | Comprehensive | 0,287741 | 0,243382 | 0,333135 |
| Verona Villafranca | O | Comprehensive | 0,288153 | 0,16236 | 0,297394 |
| Alghero Fertilia | O | Comprehensive | 0,302 | 0,098716 | 0,155806 |
| Pisa S. Giusto | S | Comprehensive | 0,259109 | 0,16236 | 0,254621 |
| Venezia Tessera | S | Core | 0,261931 | 0,254431 | 0,403863 |
| Olbia | O | Comprehensive | 0,239595 | 0,25301 | 0,25589 |
| Genova Sestri | O | Core | 0,151701 | 0,098716 | 0,081671 |

It is interesting to underline the decrease in the centrality of Rome Fiumicino, even though the airport maintains the first position in importance due to the importance of the nodes with which it is connected. There are significant increases in Catania Fontanarossa airport, Palermo Punta Raisi and Milan Linate, which assume an important role in the Italian network. Bologna, Pisa and Verona airports remain negligible.
The progressive reduction of the centrality of Genoa should be noted, which will be completely marginal in 2021, even compared to the airports of Alghero and Olbia.
The results of the three indicators shown in the figures above therefore indicate that:
• The airports of Rome and the Milan area continue to be the reference airport hubs in the peninsula, though Rome has lost its centrality due to Covid;
• The two main Sicilian airports have seen an increase in their centrality, together with the Sardinian airports and that of Lamezia Terme;
• Several airports in the centre-north are less central as the period investigated varies.

## Discussion and conclusion

It is clear that the COVID-19 pandemic has negatively impacted passenger traffic in the airport sector.

Furthermore, the research carried out shows that the geographical distance of an airport grounds compared to neighbouring urban centres continues to be a fundamental element to justify its importance and centrality.

In Italy several interesting cases emerge, such as those connected to the Sardinia region for orographic reasons and/or those connected to the airports of Palermo, Catania and

Lamezia Terme, which highlight the absence of a high-speed railway alternative within the importance of the network.

In this document, we have provided a detailed procedure to analyse a part of the Italian national air transport network, identifying the critically relevant airports in the flow of the network. The objective of this work is to identify the critical airports in the global aviation network with different centrality measures. Through a step-by-step implementation, we were able to select the most informative centrality measures.

The whole analysis should be considered for a better understanding of complex airport networks and the prevention of high-impact and catastrophic events.

This research has investigated the Italian airport network preliminarily, identifying a profound asymmetry in the centrality of the network, with some southern nodes particularly affected by national traffic.

The methodology synthetically compared the role of the various network nodes, analysing both the profiles connected with the offer and those connected with the transport demand.

The analysis was carried out by calculating, in three periods, 3 centrality indicators, with different levels of complexity about the degree of integration of the analyzed network.

Subsequent developments may take into consideration several directions of study.

The methodological approach proposed for the study of evolutionary dynamics in an aggregate way through the proposed indicators i, can be extended to other transport sectors and beyond (think, for example, of the nodes of a social network or the nodes of the worldwide web that can be reached with different navigation systems).

The results are of particular interest to airport managers and airlines as they propose strategic developments for the individual airports and therefore to set up the strategic planning of the managers and companies. The results are also useful to improve national and international policies, by verifying airport classifications and making them congruent with the actual demand data.

This can bring out contradictions between national planning done in a top-down manner (often without in-depth analysis of mobility phenomena) and the reality that determines the roles of airports in a bottom-up manner.

*References*

Arora, M., Tuchen, S., Nazemi, M., Blessing, L. (2021). “Airport pandemic response: an assessment of impacts and strategies after one year with COVID-19”, *Transportation Research Interdisciplinary Perspectives*, Volume 11, 100449.

Arvis, J. F., Shepherd, B. (2011), “The air connectivity index: measuring integration in the global air transport network”, *World Bank Policy Research Working Paper*, n. WPS 5722.

Basbas, S., Campisi, T., Georgiadis, G., Al-Rashid, M. A., Tesoriere, G., (2021), “COVID-19-19 and public transport demand trends in Sicily: analyzing external factors and governmental recommendations”, *European Transport/ Transporti Europei*, Giordano Editore, Issue 83, Paper n° 9

Benedetti, G., Gobbato, L., Perboli, G., Perfetti, F. (2012), “The Cagliari Airport impact on Sardinia tourism: A Logit-based analysis”, *Procedia – Social and Behavioural Sciences*, Volume 54, pp. 1010–1018.

Bonacich P. (1987), "Power and Centrality: A Family of Measures", *American Journal of Sociology*, Volume 92, pp.1170–1182.

Budd, L., Ison, S., Adrienne, N. (2020), "European airline response to the COVID-19 pandemic–Contraction, consolidation and future considerations for airline business and management", *Research in Transportation Business & Management*, Volume 37, 100578.

Burghouwt, G., Redondi, R. (2013), "Connectivity in air transport networks: an assessment of models and applications", *Journal of Transport Economics and Policy (JTEP)*, Volume 47, n. 1, pp. 35-53.

Campisi, T., Moslem, S., Duleba, S., Tanbay, N.A., Szmelter-Jarosz, A., Tesoriere, G. (2022), "Analysis of the effects of the first phase of COVID-19-19 pandemic on mobility choices in Italy by a multi-criteria approach", *Transactions on Transport Sciences*, Volume 3.

Cascetta, E. (2001), *Transportation Systems Engineering: Theory and Methods*, Springer: Dordrecht, The Netherlands

Cooper, A., Smith, P. (2005), *The Economic Catalytic Effects of Air Transport in Europe*, Final Report EEC/SEE/2005/004; Eurocontrol: Brussels, Belgium

De Benedictis, L., Tajoli, L. (2011), "The world trade network", *The World Economy*, Volume 34, Issue 8, pp. 1417-1454.

DPR. Decreto del Presidente della Repubblica. Regolamento Recante L'Individuazione degli Aeroporti di Interesse Nazionale, a Norma dell'Articolo 698 del Codice della Navigazione. GU n.294 del 18-12-2015. 2015. Available online: https://www.gazzettaufficiale.it/eli/id/2015/12/18/15G00213/sg

Donzelli, M. (2010), "The effect of low-cost air transportation on the local economy: Evidence from Southern Italy", *Journal of Air Transport Management*, Volume 16, pp. 121–126.

Dziedzic, M., Warnock-Smith, D. (2016), "The role of secondary airports for today's low-cost carrier business models: The European case", *Research in Transportation Business & Management*, Volume 21, pp. 19–32.

ENAC, Dati di traffico 2021, https://www.enac.gov.it/pubblicazioni/dati-di-traffico-2021

European Commission, Public Service Obligations, https://transport.ec.europa.eu/transport-modes/air/internal-market/public-service-obligations-psos_en

Eurocontrol, https://www.eurocontrol.int/covid19

Fagiolo, G., Mastrorillo, M. (2014), "Does Human Migration Affect International Trade? A Complex-Network Perspective", *PLoS ONE*, 9(5): e97331

Givoni, M., Dobruszkes, F. (2013) "A Review of Ex-Post Evidence for Mode Substitution and Induced Demand Following the Introduction of High-Speed Rail", *Transport Reviews*, 33:6, pp. 720-742.

Grimme, W., Maertens, S., Schröpfer, A. (2018), "Options for Traffic Growth at Smaller European Airports under the European Commission's Guidelines on State Aid", *Transportation Research Procedia*, Volume 35, pp. 130–139.

Hakfoort, J., Poot, T., Rietveld, P. (2001), "The regional economic impact of an airport: The case of Amsterdam Schiphol Airport", *Regional Studies*, Volume 35, pp. 595–604.

Haveliwala, T., Kamvar, S. (2003) "The Second Eigenvalue of the Google Matrix", Technical Report, Stanford

Iapadre, P. L., Tajoli, L. (2014), “Emerging countries and trade regionalization. A network analysis”, *Journal of Policy Modeling*, Volume 36S, pp. S89–S110, https://doi.org/10.1016/j.jpolmod.2013.10.010

ICAO,https://www.icao.int/sustainability/Documents/Covid19/ICAO_coronavirus_Econ_Impact.pdf

Kazda, A., Badanik, B., & Serrano, F. (2022), “Pandemic vs. Post-Pandemic Airport Operations: Hard Impact, Slow Recovery”, *Aerospace*, 9(12), 810.

Laurino, A.; Beria, P., Debernardi, A., Ferrara, E. (2019), “Accessibility to Italian remote regions: Comparison among different transport alternatives”, *Transport Policy*, Volume 83, pp.127-13

Laurino, A., Beria, P. (2014), “Low-cost carriers and secondary airports: Three experiences from Italy”, *Journal of Destination Marketing & Management*, Volume 3, pp. 180–191

Lupi, M. (2007), *Linee Guida per la Programmazione Dello Sviluppo Degli Aeroporti Regionali*, Progetto di Rilevante Interesse Nazionale, FrancoAngeli Editore: Milano, Italy

Perron, O. (1907), "Zur Theorie der Matrices", *Mathematische Annalen*, 64 (2), pp. 248–263, doi:10.1007/BF01449896

Reg UE 1315 e 1316 del 2013, https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex%3A32013R1315, https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=CELEX:32013R1316&from=DA

Ruhnau, B. (2000), “Eigenvector-centrality — a node-centrality?”, *Social Networks*, Volume 22, Issue 4, 2000, Pages 357-365, ISSN 0378-8733.

Socorro, M. P., Betancor, O. (), “Air transport subsidies for resident passengers: The unexpected effects on competition”, *Research in Transportation Economics*, Volume 79, 100772.

Sun, X., Zhang, Y., & Wandelt, S. (2017) “Air transport versus high-speed rail: an overview and research agenda”, *Journal of Advanced Transportation*.

Redondi, R., Malighetti, P., Paleari, S. (2013), “European Connectivity: The role played by small airports”, *Journal of Transport Geography*, Volume 29, pp. 86–94.

Tantardini, M., Ieva, F., Tajoli, L., Piccardi, C., (2019), “Comparing methods for comparing networks”, *Sci Rep* 9, 17557.

Trans-European Network on Transportation (TEN-T,), https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

Tuchen, S., Arora, M., & Blessing, L. (2020). Airport user experience unpacked: Conceptualizing its potential in the face of COVID-19. Journal of air transport management, 89, 101919.

Tveter, E. (2017), “Effects of airport accessibility on regional development: Evidence from implementation of regional airports in Norway”, *Research in Transportation Economics*, Volume 63, pp. 50–58.

Xia, W., Zhang, A. (2016) “High-speed rail and air transport competition and cooperation: A vertical differentiation approach”, *Transportation Research Part B: Methodological*, Volume 94, pp. 456-481.

York Aviation (2004), *The Social and Economic Impact of Airports*, ACI-Europe: Geneva, Switzerland.