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Adapting Connectivity Measure for Business Aviation – COVID-19 Case Study

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Abstract

This article introduces an adaptation of Flow centrality connectivity measure to business aviation. It demonstrates its potential in the COVID-19 case study, where a significant drop in traffic was observed. Its Connectivity Indicator shows a connectivity paradox during 2020, when connectivity values slightly decreased at first and subsequently exceeded their 2019 values during summer, indicating that airports were connected more effectively compared to the previous year. It is demonstrated in more detail by the examples of airports with the best and worst connectivity during April 2020 and explains the difference in their connectivity value and the number of flights in the context of the pandemic. The results show the potential of this two-dimensional measure in the sector and provide a foundation for further research on business aviation connectivity as a valuable tool for business aviation charter companies to optimize their operations. The study also outlines the economic value of business aviation for Europe and presents different flight missions carried out in this sector, including its key role of conducting medical and repatriation flights during the pandemic.

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Peer-review under responsibility of the scientific committee of the 11th International Conference on Air Transport –INAIR 2022, Returning to the Skies

Keywords: business aviation; connectivity; COVID-19; flow centrality

1 Introduction

The main purpose of this article is to introduce an adaptation of the Flow centrality measure to business aviation. As presented by the OECD (2017), there are many connectivity measures for airline operations, on the contrary, the performance of business aviation is classified mainly by the number of flights between airports, and there is hardly...
any other approach excluding degree and weighted degree. This article focuses on finding a more complex approach to evaluate the performance of business aviation with respect to its properties and principles. The proposed approach could provide a method for business aviation airport classification, as well as a tool for business aviation charter companies to plan their flight schedules more effectively, optimize their operations, and therefore increase their profits. Furthermore, it could serve as a base for future research, where this approach will be refined more or to create new approaches to evaluate the performance of business aviation, based on connectivity measures.

Although it is a very important part of aviation, in fact, it is considered as the consequence of the development and global extension of traditional aviation among the general public and, as Oxford Economics (2012) and Booz et al. (2016) show in their studies, has a great impact on the economy, connectivity, and many other aspects; Fichert et al. (2020) and Budd and Graham (2009) conclude that this field seems to be overlooked by the academic community and only a small amount of scientific work has been done in this sector of aviation.

According to Budd and Graham (2009), the number of airline passengers has been scaling up since the mid-1980s to the point where the airline industry became the victim of its own success. The limited capacity of both airports and airways began to cause delays, creating large-scale costs for the entire industry and the global economy through lost productivity. Schumer and Maloney (2008) claim that delays or cancelations cost both airlines and passengers a billion dollars per year. Furthermore, as Budd and Graham (2009) concluded in their research, the dissatisfaction of passengers, especially business and first-class travelers, began to slowly form the business aviation market. Today, business aviation has a great economic impact in all regions. According to the EBAA’s Yearbook (2021), business aviation created an economic output of €62.7 billion and provided more than 294,000 direct or indirect jobs in Europe in 2021.

Business aviation offers a comfortable and pleasant travel, according to the schedule and preferences of the passengers. It includes improved time and cost efficiency, improved personal safety, reduced opportunities for industrial espionage, access to a wider range of airports, and, as Budd and Graham (2009), Andersen (2001) and Oxford Economics (2012) agree, increased employee productivity. According to surveys previously presented by Hankovská (2017) and Oxford Economics (2012), the main reason customers prefer business aviation is to save time. However, business aviation is not only focused on business travelers. Operations in this sector also include medical and repatriation flights. Its fleet flexibility, quick reaction times, and ability to fly to smaller, more challenging airports make business aviation a great way to provide help. For example, according to IBAC (2020), there were about 70 repatriation flights a day during the COVID-19 pandemic, demonstrating that business aviation aircraft can quickly and efficiently transport patients for their treatment, whether by helicopters, turboprops or jet airplanes.

During spring 2020, both airline and business aviation experienced a significant decrease in flights, when the COVID-19 pandemic started in Europe. However, according to EBAA (2020), business aviation was able to meet its pre-covid numbers already during August 2020, when the airlines were still at almost -60% of its activity. EBAA (2021) also states that business aviation was also able to even exceed its numbers during 2021.

Most connectivity measures are tailored to the airlines’ hub-and-spoke operation network and consist of parameters that are not relevant to business aviation. The OECD (2017) assessment of connectivity models mentions different measures based on connecting time, airport capacity, the fastest route, travel cost, number of connections, etc. However, for example, often taken into account, indirect connections have no value for business aviation passengers, since they demand direct flights between destinations to avoid time-consuming transfers. This fact also eliminates parameters like minimum connecting time or the fastest path. Also, the number of available seat capacity or the number of passengers is not very relevant, because clients pay for the whole plane, regardless of the number of seats occupied. These principles make most of the measures inapplicable to business aviation. On the basis of the above mentioned, the main goal of this study is to find a suitable connectivity measure to adapt to the sector of business aviation.

2 Materials and Methods

Because the flight requests of clients determine the operation of business aviation charter companies, the objective was to find a connectivity measure from the perspective of these companies, trying to assess the most sought-after airports. This means that the most important parameter will be the number of flights from the airport or the continuity between inbound and outbound flights at the particular airport. Therefore, it should be, according to the definitions of Malighetti (2008) and Burghouwt et al. (2013), a centrality-based model without any inapplicable parameters that
distort the results, so it is possible to analyze the importance of each node (airport) in the network and, hereby, determine the core network of business aviation airports in Europe.

2.1 Data Acquisition

Generally speaking, the acquisition of business aviation data is not an easy task. Due to the privacy of clients, charter companies do not share their schedules, so the main source is ADS-B data. Data used for the purposes of the research were provided by the European Business Aviation Association (EBAA), which is the largest European organization representing more than 700 members of the European business aviation sector. The main data source was their E-STAT Dashboard, the interface with the possibility of filtering the data by month, country, airport, and aircraft. Its Top Airport Pairs provided information about the number of flights between each pair of airports in the given time interval. The limitation of the data was the minimal filtrable time interval, which is one month. To obtain the most accurate values as possible, this interval was selected. Additionally, to obtain only flights within Europe, only departures and arrivals to/from Europe were selected.

2.2 Data Processing

Data were exported for every month from January 2019 to December 2021 for both the Arrival and Departure Dashboards. For further processing, it was necessary to unite the data from the Departure and Arrival Dashboards to eliminate the possibility of missing flights in one of the sources. Data for one month contained approximately 5 to 20 000 unique airport pairs, 18 to 70 000 flights, and there were around 1 200 active airports.

During data processing, data inconsistency was discovered. For some airports, the numbers of arrivals and departures were too different to correspond with real numbers. In some cases, the difference was in hundreds of flights. This issue was solved by removing the turboprop aircraft from the filter due to its possible flight coverage errors. The next phase of data processing was to calculate the degree and weighted degree of airports using Gephi, a free software for network visualization and calculating network parameters (Bastian, 2009).

2.3 Data Analysis

As mentioned above, business aviation charter companies operate on point-to-point manner according to the demand and try to optimize their operations to connect their flights from individual destinations as smoothly as possible to minimize the number of empty unprofitable flights. Also positioning an aircraft into the network to receive a flight request from its position or nearby as soon as possible is an important task. Déniz et al. (2013) developed a new measure of airport connectivity based on flow centrality measure by Freeman et al. (1991), which is completely demand-based. It is focused on airports and their role in the network from both traffic generation and connectivity perspective.

The original indicator presented by Freeman et al. (1991) contains the following principles. The flow \( m \) travels between two nodes, origin \( j \) and destination \( k \) through the intermediate node \( x_i \). For all nodes involved in transmission, the incoming and outgoing flow must be equal. The total flow that travels through the node is divided by the total flow between all pairs of nodes where the node is neither a source nor a destination, so the centrality measures the proportion of the total flow that travels through the particular node and is valued between 0 and 1.

\[
C_f(x_i) = \frac{\sum_{j<k} \sum_k m_{jk}(x_i)}{\sum_{j<k} \sum_k m_{jk}}
\]

Déniz et al. (2013) adapted this indicator and defined two separate measures, traffic generation and connectivity, to measure the contribution of airport traffic to the network in two-dimensions. “The traffic generation \( OD_i \) is the ratio between the passengers that either originate or terminate at the airport \( i \) \( OD_i \) and the total network passengers \( P \). The second measure is the flow centrality indicator \( C_i \) and measures the airport’s importance as a connecting
point. It is calculated as the ratio between connecting passengers (ci) and total network passengers that do not originate or terminate at the airport (P – od).” (Rodríguez-Déniz, 2013).

\[
OD_i = \frac{od_i}{P}
\]  

\[
C_i = \frac{c_i}{P - od_i}
\]

Adaptation to business aviation was done mainly by changing the perspective from which connectivity is assessed. From the perspective of a charter company, connectivity is the ability to receive a request for a connecting flight from the particular airport. The flow is in our case flights inside the examined network and airports remain being the nodes.

Having two indicators seems to be very convenient for the business aviation sector as well since both traffic generation and connectivity are important for the sector. The Traffic Generation Indicator could indicate airports where airplanes stayed for longer period of time; therefore, identify hubs, services, or different reasons for longer aircraft parking. Apart from that, Flow Centrality Indicator could indicate airports with the largest amount of connecting flights, therefore, airports with the biggest success rate of getting connecting flight.

The actual values used in the calculation are described below.

\[
od_i = \text{weighted indegree}_i - \text{weighted outdegree}_i
\]

\[
c_i = \text{weighted degree}_i - \text{weighted indegree}_i - \text{weighted outdegree}_i = \text{weighted degree}_i - |od_i|
\]

\[
P = \sum \text{all flights within the network}
\]

Since the Traffic Generation Indicator (ODi) represents the difference between the number of inbound and outbound flights divided by all flights within the network, the greater the indicator, the better the airport is in traffic generation. The Flow Connectivity Indicator (Ci) shows continuity of flights at the airport, meaning the greater the indicator is, the better connectivity the particular airport offers. The article is focused on connectivity, therefore, only Flow Connectivity Indicator will be used for further connectivity assessment.

As already mentioned, the European business aviation network during 2019-2021 consists of almost 1200 active airports. It was necessary to narrow the selection to the most important airports in the network and then subject these airports to further analysis. This was achieved using boxplot data visualization and evaluation. Apart from visualization of the distribution of data values, it identifies data outliers, the atypical observation that does not fit into probabilistic behavior of the dataset. In this case, it was a value more than 1.5 times the interquartile range (IQR) above the 3rd quartile. The assessed values were Ci values for each month of year 2019 separately.

The next step was to compare the number of outliers for every month of 2019 and only airports that occurred as outliers for every month of 2019 were chosen. The aim was to identify the core network of standard business aviation operations in 2019 and to analyze its behavior during the COVID-19 pandemic in 2020. This selection identified 61 airports as the core network.

Data for core network airports were also normalized using z-score normalization. As Aksu (2019) claims, this normalization method uses mean (μi) and standard deviation (σi) of each variable (xi) for the entire dataset to normalize the vector of each feature. The values of z-score indicate the distance of the raw value from the arithmetic mean. The mean is represented by a value of 0.
$x' = \frac{x - \mu_i}{\sigma_i}$

(7)

### 3 Results

Five airports with the best and worst Connectivity Index z-score values during April 2020 when the biggest decline in traffic was observed, were chosen. Table 1 shows the values of the best airports.

Table 1. Top 5 airports, comparison of April 2020 and 2021 to April 2019

| ICAO Code | Flights 2019 | Ci 2019 | Flights 2020 | Ci 2020 | Δ flights 2019 | Δ Ci 2019 | Flights 2021 | Ci 2021 | Δ flights 2019 | Δ Ci 2019 |
|-----------|--------------|---------|---------------|---------|----------------|-----------|---------------|---------|----------------|-----------|
| EDDM      | 939          | 0.0268  | 384           | 0.0440  | -59%           | -64%      | 800           | 0.0282  | -15%           | 5%        |
| EDDN      | 297          | 0.0084  | 243           | 0.0277  | -18%           | 228%      | 303           | 0.0107  | 2%             | 26%       |
| ENGM      | 254          | 0.0072  | 188           | 0.0216  | -26%           | 199%      | 162           | 0.0056  | -36%           | -23%      |
| LIMC      | 241          | 0.0068  | 136           | 0.0151  | -44%           | 123%      | 216           | 0.0074  | -10%           | 9%        |
| UUEE      | 293          | 0.0081  | 134           | 0.0151  | -54%           | 86%       | 192           | 0.0066  | -34%           | -18%      |

Although their number of flights decreased during 2020, their Connectivity Indicator value increased even by hundreds of percent in some cases. This indicates that these airports, despite the decrease in the number of flights, connected the largest volume of flights during April 2020, since the connectivity index represents the ratio to the total number of flights in the network.

The same comparison was done with the 5 worst airports during April 2020 in terms of connectivity z-score. Table 2 shows the comparison of the number of flights and connectivity values for April 2020 and 2021 to April 2019 for each airport. Unlike the top 5 airports, these airports reported a decrease in both the number of flights and the Connectivity Indicator values. This indicates that they connected a smaller proportion of flights during the most critical month.

Table 2. Worst 5 Airports, comparison of April 2020 and 2021 to April 2019

| ICAO Code | Flights 2019 | Ci 2019 | Flights 2020 | Ci 2020 | Δ flights 2019 | Δ Ci 2019 | Flights 2021 | Ci 2021 | Δ flights 2019 | Δ Ci 2019 |
|-----------|--------------|---------|---------------|---------|----------------|-----------|---------------|---------|----------------|-----------|
| EBAW      | 303          | 0.0087  | 42            | 0.0044  | -86%           | -49%      | 234           | 0.0081  | -23%           | -7%       |
| EGIJ      | 365          | 0.0105  | 14            | 0.0016  | -96%           | -84%      | 165           | 0.0058  | -55%           | -45%      |
| EGJK      | 256          | 0.0071  | 36            | 0.0042  | -86%           | -41%      | 211           | 0.0076  | -14%           | 6%        |
| LGGG      | 1811         | 0.0517  | 254           | 0.0288  | -86%           | -44%      | 1525          | 0.0533  | -16%           | 3%        |
| UUWW      | 1323         | 0.0375  | 166           | 0.0182  | -87%           | -52%      | 1297          | 0.0457  | -2%            | 22%       |

Fig. 1 shows the average value of the Connectivity Indicator (thick lines) and range of values (colored areas) before (2019) and during the COVID-19 pandemic (2020, 2021). It presents the COVID-19 connectivity paradox, where the connectivity indicator values do not show any significant impact of the pandemic, in contrast to a strong decrease in flights (Figure 2). There is only a very slight decrease in April and, in contrast, an increase in connectivity during the summer months. This indicates that the airports were able to connect flights more effectively despite their reduced number.
As mentioned, the number of flights (Figure 2) does not completely correspond to the value of the Connectivity Indicator, as the indicator represents the ratio of connected flights and the number of total network flights in a certain period. Therefore, it can be said that overall connectivity in the selected core network was not significantly affected by the pandemic; however, the effects can be observed in individual airport cases.
4 Discussion

The data acquired for the research were limited by the interval of one month; therefore, the results do not reflect the situation in such detail as could possibly be achieved. Also, flights could not be filtered to contain only commercial flights without empty legs, so all types of flight missions are included. However, it could adequately represent the behavior of connectivity in individual years.

A detailed view of the top and worst 5 airports during April 2020 showed that the values of the Connectivity Indicator, adapted to the business aviation network, may not always correlate with the number of flights, since it represents the ratio of flights to the number of total network flights for the given interval. Thus, the Connectivity Indicator represents a proportion of the total traffic volume connecting through the particular airport taking into account the current network properties. This makes the indicator sensitive to airport connectivity fluctuations regardless of reduced or increased number of total network flights at the particular moment, thus identifying airports that significantly increased or decreased their connectivity in that time and subsequently gives an opportunity to analyze links between the connectivity values and other factors affecting airports operations.

In case of the top five airports, during April 2020, the connectivity showed better values, even by hundreds of percent, in contrast to almost 70% decline in number of flights. The best connectivity values were recorded at the airports EDDM (Munich) and EDDN (Nuremberg), where Nuremberg reached a 228% increase in connectivity compared to April 2019. Further analysis could show the strongest connections at that time; furthermore, when supplemented with travel restrictions and other factors, it could give us a complete picture of the behavior and its probable causes. For example, according to Eurocontrol (2020), Lufthansa group, the largest German airline, significantly decreased its operations during April, grounding 700 out of its total 763 aircraft; however, flights within the European Union and Schengen were still allowed, as well as flights to Great Britain, Switzerland, Norway, Iceland, and Liechtenstein. This could form the tendency to look for other forms of travel for the passengers, therefore shape the demand for business aviation, and cause an increase of connectivity at these German airports.

As mentioned, connectivity characteristics are incomparable to the number of flights. The difference can be observed in Figure 1 for connectivity and Figure 2 for the number of flights. Unlike connectivity, number of flights reported a significant drop in spring 2020 and steady return to its pre-covid numbers. Connectivity shows only a slight drop in spring, followed by an increase in its average values during summer, this indicates the flights were better connected due to greater demand. In general, the effect of the COVID-19 pandemic on the connectivity of the core network was not as significant as on the number of flights. The connectivity values for 2021 have very similar behavior to those for 2019, but their average values are slightly better. This could indicate the persistent increase in demand as new passengers continue use business aviation instead of airlines. In addition, the number of network flights exceeded its 2019 numbers during summer 2021 confirming the trend. However, the ability to compare these values is not as important since connectivity reflects the demand for flights from destinations with respect to the number of all network flights at that time.

Unfortunately, since no other approach to measuring connectivity within the business aviation sector, it is difficult to verify the results in more detail. Future, more detailed research could identify strengths and weaknesses of the proposed measures.

5 Conclusion

In conclusion, this article demonstrates the value of business aviation in Europe, as the well as potential of Flow centrality adaptation to this sector. Although only large data intervals were available, it was able to demonstrate the behavior of business aviation connectivity before and during the COVID-19 pandemics. It discovered significant differences in airport connectivity response during the pandemic, which did not completely correlate with the number of flights at the airport. It also points out that the airport’s connectivity should be related to the current number of all network flights.

To reliably determine core network airports, it is necessary to have data with the smallest possible time interval, ideally in days or hours, and the possibility to filter only commercial flights, empty legs or other flight missions as required. Future research should also focus on adapting the formula to take into account the difference between customer and empty flights to better reflect the demand. The full potential of Flow Centrality adaptation to business
aviation could be subsequently reached by including the second indicator, Traffic Generation, in the analysis. These indicators could provide a valuable insight into demand and serve as a tool for business aviation charter companies for optimization of their flight scheduling, thus to generate more profit. The other utilization could be found in airport classification, where it could identify the different patterns in airport behavior through the year and even find groups of airports that behave similarly to the events. The article should also emphasize the role of business aviation in Europe both before and during the pandemic, not only as an airline substitution, but also in terms of medical and repatriation flights. When the airline flights were still at its lowest, business aviation exceeded its pre-pandemic numbers. Not only does the pandemic show the importance of the sector, business aviation plays a crucial role in aviation in the long term. Despite the fact, only a small amount of academic work deals with this undoubtedly important part of aviation. Future research should give us important knowledge, for example, in terms of its operating principles or economic importance and help with its further development.

Acknowledgments

The authors would like to thank to EBAA and WingX for their data provision and consultations.

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