Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Investigating and Identifying Critical Airports for Controlling Infectious Diseases Outbreaks

Paraskevas Nikolaou and Loukas Dimitriou*

*Lab. for Transport Engineering, Department of Civil and Environmental Engineering, University of Cyprus

Abstract

The enormous economic impact of air transportation networks on a local, national, and international level has created an interest for further investments and increased the complexity of the global air transport network. The increased number of worldwide airport passengers and of the aircraft movements and also of the international airport cargo shipments is evident. Therefore, the functionality of this complex air transport network is very important and requires to be investigated and evaluated for identifying the airports that appear to be critical to this network. However, besides the economic benefits that air transport network is offering in local, national and international level through their services (shipments of goods and transport of passengers) play an ever-increasing role in safeguarding global health security. This paper investigated the global air transport network for identifying the airports that may constitute a public health event of international concern from infectious diseases (e.g. COVID-19). In detail, critical airports, in terms of centrality measures (e.g. Closeness, Degree, Betweenness, and Page Rank Centrality) were identified and addressed by pointing them to global authorities for suggesting and implementing routine prevention and control measures for possible future disease outbreaks.

© 2020 The Authors. Published by ELSEVIER B.V.

Peer-review under responsibility of the scientific committee of the 23rd Euro Working Group on Transportation Meeting

Keywords: Disease spreading; Betweenness centrality; Degree centrality; Closeness centrality; Page rank centrality; Critical airports.

1. Introduction

The rapid aviation development that is taking place in the last decades is apparent. The International Air Transport Association (IATA) revealed that the current trends in air transport suggest that passenger numbers could double to
8.2 billion in 2037 (IATA, 2020). In this case, the air transport network will become denser and thus more complex, a fact that will create more challenges for the policymakers especially in case of an infectious disease outbreak.

The combination of aviation development with the highly globalized world has increased the likelihood of infectious diseases spreading rapidly between countries and continents questioning the safety measures that each airport follows and limiting people’s desire and freedom to travel. However, the question that must be answered first is the identification of the “critical” airports that are prone to a disease outbreak.

Several studies in the literature have been implemented for analyzing disease spreading patterns (e.g. Nikolaou and Dimitriou, 2019). For instance, Warren et al., (2010) conducted a background review on existing literature concerning pathologies of travel considering UK media representations of the first ‘wave’ of the spread of the 2009 H1N1 virus. Strona et al., (2018) studied the vulnerability of networks to epidemics. The results of his study revealed that the density of infection pathways had a stronger effect on outbreak magnitude than the epidemic parameters when a broad range of network topology is considered. Poletto et al., (2013) revealed that the epidemic spreading procedure has an acceleration when the length of stay increases, depending also on the dominant role of the hubs, however, the epidemic spreading delays when the spreading potential of the hubs is substantially reduced. In Enright and Kao’s, (2018) work, they defined methods based on network dynamics for modeling epidemic spreading among specialists, and presented the opportunities and difficulties in working within a disease-relevant network. Merler and Ajelli, (2010) studied the epidemic transmission rate in households, schools, workplaces, and in the general population of 37 European countries. Addressing the metapopulation epidemic dynamics is critical for setting barriers to epidemic spreading. Therefore, several approaches have been taken, such as reducing mobility rates (Gong et al., 2013). Nikolaou and Dimitriou (2020) identified the critical airports on the globe that appear with a high possibility of initiating a disease outbreak. The disease was hypothesized that it was originated from the most popular airports in three continents (Africa, Asia, and South America).

This paper analyzes the complexity of the global air transport network, incorporating 7,698 airports and taking into consideration 66,771 routes. Figure 1 shows the location of international airports and the routes/connections between the airports. Therefore, the objective of this study tries to answer the following questions. Which centrality measures are more suitable for this complex air transport network? On which airports should we turn our focus on preventing a global disease outbreak?

![Fig. 1. Location of international airports and the routes/connections between them.](image)

This paper analyses the complexity of the global air transport network and identifies the critical airports by implementing different centrality measures such as Betweenness centrality, Degree centrality, Page Rank centrality, and Closeness centrality.
In addition, this analysis will be able to finger point the airports that are necessary to be addressed and equipped in a way that they will be able to discover infected passengers. However, it must be noted that the different centrality measures will provide different results which will be discussed and analyzed for distinguishing the most informative centrality measure. This variety of results will create a realistic “picture” of the airport’s criticality. Additionally, this approach will also provide information on how well connected are global airports between them, a fact that is also very important in the setting measures approach for getting prepared for a future disease outbreak by giving attention to specific routes originated or destined from and to critical airports. The structure of the paper was developed in a way for providing the weak nodes (airports) for an investigation of disease spreading phenomena over the globe by examining the complexity of the global airport network.

The rest of the paper is organized as follows. Section 2 provides a brief description of the analysis that was implemented and presents the overall outcome from the implementations of the methodological framework. Conclusions are reported in the final section.

2. Applications and Results

This study focuses on the structure of the air transport network based on a complex connectivity matrix between countless airports all over the globe. Evidence, from recent events of COVID-19 the understatement of the global air transport network is of vital importance.

2.1. Centrality Analysis

This paper developed a centrality analysis using different measures of centrality for identifying the important actors (airports) in the global air transport network. The centrality measures that were used in this paper are namely, degree, betweenness, closeness, and page rank each one having different characteristics. The data that was obtained and used in the centrality analysis concern the location of the global airports and their connections with other airports (routes) (OpenFlights, 2020).

Degree centrality can be characterized as the simplest measure of centrality and it measures the edges (links) that each node (airport) has. Betweenness centrality finds the airports between an origin and destination locations that create the shortest path for moving from origin to destination.

Closeness centrality also considers the shortest paths between airports. Closeness is considered as reciprocal of farness where farness for a given airport is the average distance from that airport to all other airports. Page rank centrality measures the number and quality of links (routes) to an airport in order to estimate the importance of an airport.

These four centrality measures have been implemented and the results can be depicted in Figure 2. As can be seen from the figure, closeness centrality did not obtain any significant result of the global airports’ criticality. Therefore this measure was not considered for interpretation. As for the other measures, it seems that their outcome is quite similar but to a different extent (size of circle). Most of the critical airports appear to be in Europe and North America followed by the countries China, Russia Australia, and the countries of middle Africa. Therefore, the conclusion from this implementation is that we were able to obtain a general picture of the critical airports which if kind expected if we consider the evolution of the recent pandemic (COVID-19) which initiated from China who has critical airports and transferred to Europe and America where the majority of the critical airports are located there. The next question raised through this methodological framework was: Which centrality measure should be trusted from betweenness, degree, and page rank centrality and how this can be justified? Therefore, the next sub-section was developed.
Fig. 2. (a) Degree centrality; (b) Betweenness centrality; (c) Closeness centrality; (d) Page rank centrality.

2.2. Selection of Centrality Measure

This sub-section has been developed for distinguishing the most informative centrality measure between the measures Betweenness centrality, Degree centrality, and Page Rank centrality, using Principal Component Analysis (PCA) a dimensional reduction technique.

Fig. 3. Contribution of Centrality measures.
In detail, all three measures were concerned as variables and therefore by using PCA and thus the centrality measures which are correlated with the principal components are the most important in identifying the central nodes. Figure 3 presents the centralities that have more information about central airports. As it is shown in the plot, Page Rank and Degree Centrality have the most contribution value among the three centrality measures and therefore they can determine the central nodes more accurately than the chosen centrality.

The next implementation was the observation of the critical measures’ relationship. Figure 4 presents the relationship between Degree and Page Rank centralities of the global air transport network. In particular, they seem to have a linear relationship, and as the degree centrality increases also the page rank centrality increases denoting a strong relationship. From this approach, we were able to identify the metrics that are suggested to be used in such complex networks.

![Fig. 4. Relationship between degree and page rank centrality](image)

### 2.3. World’s Busiest Airports

This sub-section will present the top 10 global airports based on the two different metrics degree centrality and page rank centrality and the outcomes will be compared between them and with also the top 10 world’s busiest airports based on the total passenger traffic (Airports Council International). Table 1 presents all the results.

As can be observed from the table centrality measures identified the first critical airport in the world, namely “Hartsfield-Jackson Atlanta International Airport” which is also ranked as first in the Airports Council International. The resulted critical airports from the two measures are very similar between them but with slight differences in sortation. In addition, the results of the two centrality measures found 6 out of 10 world’s busiest airports based on the list of Airports Council International, a fact that shows the correctness of the two centrality measures.

Here it must be noted that the list of Airports Council International with the world’s busiest airports is based on the total passenger traffic in contrast with the information used from degree and page rank centralities which were only the network of connected airports. In particular, it seems that analyzing complex networks (likewise the global air transport network) by knowing only its structure (nodes-airports and links-routes) can and will provide the correct information without bothering collecting data that might be biased.

Overall, the outcomes of this study can be used from Health and Safety air transport authorities for understanding the dynamics of a disease spreading scenario over the air transportation network for preventing a pandemic in the future.
2.4. Focusing on Europe

As it has been proved from the different centrality measures the European air transport network constitutes one of the most complex air transport networks in the global air transport network. One again a centrality analysis has been developed for analyzing this network and for identifying the important, thus critical airports that are more expected to work as hubs for a pandemic outbreak in the region of Europe. As has been referred above the centrality measures that were used for this purpose are the Degree and Page Rank centrality which have been proved as the most informative centrality measures. Table 2 presents the most important airports based on these two measures.
Table 2. European most busy airports are based on Degree and Page Rank centrality measures.

| Degree Centrality | | | | |
|---|---|---|---|
| # | Country | Airport Name | IATA Code |
| 1 | United Kingdom | Heathrow Airport | LHR |
| 2 | France | Aéroport de Paris-Charles de Gaulle | CDG |
| 3 | Germany | Flughafen Frankfurt/Main | FRA |
| 4 | Netherlands | Amsterdam Airport Schiphol | AMS |
| 5 | Belgium | Brussels Airport | BRU |
| 6 | Austria | Vienna International Airport | VIE |
| 7 | United Kingdom | Manchester Airport | MAN |
| 8 | Italy | Leonardo da Vinci–Fiumicino Airport | FCO |
| 9 | Spain | Málaga Airport | AGP |
| 10 | Sweden | Stockholm-Arlanda Airport | ARN |

| Page Rank Centrality | | | | |
|---|---|---|---|
| # | Country | Airport Name | IATA Code |
| 1 | France | Aéroport de Paris-Charles de Gaulle | CDG |
| 2 | United Kingdom | Heathrow Airport | LHR |
| 3 | Germany | Flughafen Frankfurt/Main | FRA |
| 4 | Spain | Palma De Mallorca Airport | PMI |
| 5 | France | Paris-Orly Airport | ORY |
| 6 | France | Charles de Gaulle International Airport | CDG |
| 7 | Norway | Oslo Lufthavn | OSL |
| 8 | Germany | Düsseldorf Airport | DUS |
| 9 | Ireland | Dublin Airport | DUB |
| 10 | Finland | Helsinki Vantaa Airport | HEL |

As can been observed the two centrality measures showed the same three most important airports inside the European air transport network (though in a different order), a fact that validates the criticality of these airports. As for the rest of the airports, it seems that they are not the same. Figure 5 shows the critical European airports based on the different measures of centrality. Concerning the degree centrality, it seems that the critical airports cover almost all the European regions, however, concerning the page rank centrality the critical airports are more concentrated on the west side of Europe. If we recall the dynamic spread of COVID-19 inside the European region we will see that there are similarities with the degree centrality were the first countries that were hit from the virus were Italy, Spain, France, Germany, etc, where these countries’ airports were identified as critical. Concluding, analyzing the air transport network of Europe can provide significant information on which airports are essential to be taken under consideration especially in the case of the second wave of COVID-19.

Fig. 5. Critical European airports based on: (a) Degree centrality; (b) Page rank centrality
3. Conclusions

In this paper, we have provided a step-by-step procedure for analyzing the complex global air transport network and identifying critical-important airports in the flow of the network. Nowadays, we all are witness to the enormous spreading of the pandemic COVID-19 thought air mobility. Victims to this pandemic are important yet critical airports that form a link with other critical airports all over the world helping the quick spread of the virus.

The objective of this paper is to identify the critical airports in the global air transport network using the different centrality measures (e.g. degree, betweenness, closeness, and page rank centrality). Through the step-by-step implementation, we were able to select the most informative centrality measure which was degree and page rank centralities, which appeared to have a strong relationship between them. The next implementation was able to characterize these two centrality measures as the most appropriate for this purpose while they identified six out of the ten busiest airports from the list of Airports Council International. The encouraging thing in this implementation was the fact that no information on passenger traffic was used but only the structure of the global air transport network. The entire analysis should be considered for a better understanding of these complex networks and for preventing unpleasant situations.

4. Online license transfer

All authors are required to complete the Procedia exclusive license transfer agreement before the article can be published, which they can do online. This transfer agreement enables Elsevier to protect the copyrighted material for the authors but does not relinquish the authors’ proprietary rights. The copyright transfer covers the exclusive rights to reproduce and distribute the article, including reprints, photographic reproductions, microfilm, or any other reproductions of similar nature and translations. Authors are responsible for obtaining from the copyright holder, the permission to reproduce any figures for which copyright exists.

References

Airports Council International. 2020. [online] Available at: <https://aci.aero/wp-content/uploads/2019/03/2486_Top-20-Busiest-Airport_passenger_v3_web.pdf> [Accessed 11 June 2020].

Clark, T., Woodley, R., De Halas, D., 1962. Gas-Graphite Systems, in “Nuclear Graphite”. In: Nightingale, R. (Ed.). Academic Press, New York, pp. 387.

Deal, B., Grove, A., 1965. General Relationship for the Thermal Oxidation of Silicon. Journal of Applied Physics 36.2, 37–70.

Deep-Burn Project: Annual Report for 2009. Idaho National Laboratory, Sept. 2009.

Fachinger, J., den Exter, M., Grambow, B., Holgersen, S., Landesmann, C., Titov, M., Podruhzina, T., 2004. Behavior of spent HTR fuel elements in aquatic phases of repository host rock formations, 2nd International Topical Meeting on High Temperature Reactor Technology. Beijing, China, paper #B08.

Fachinger, J., 2006. Behavior of HTR Fuel Elements in Aquatic Phases of Repository Host Rock Formations. Nuclear Engineering & Design 236.3, 54.

Nikolaou, P., and Dimitriou, L. Investigation of the European Airport System Robustness against Infectious Diseases Spreading through the Airline Network: Results from Extensive Stress-tests. 99th Transportation Research Board Annual Meeting, 2020, Washington 51 D.C., U.S.A

Nikolaou, P. and Dimitriou, L., 2020. Identification of critical airports for controlling global infectious disease outbreaks: Stress-tests focusing in Europe. Journal of Air Transport Management, 85, p.101819.

Openflights.org. n.d. Openflights.Org: Flight Logging, Mapping, Stats And Sharing. [online] Available at: <https://openflights.org/> [Accessed 20 August 2020].