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Introduction

The airline industry has grown significantly in recent years, with the number of passengers and flights continually increasing. Annually, the airline business brings in billions of dollars for the world economy. It is estimated that the global airline industry made $838 billion in 2019, which is about 2% of the world's GDP. (Revenue of Airlines Worldwide 2023 | Statista). This shows that the airport industry has a big impact on the economy and highlights how important it is to manage the complicated nature of transport by air smoothly. I'm interested in social networks and how math can be used in real life, so learning about how complex network analysis is used to show and evaluate real-life airport performance and risk was very interesting to me, even in a theoretical sense.

Reviewing three studies provided me with some insight into the use of complex networks: Bagler G.'s "Complex Network View of Performance and Risks on Airport Networks," Malik H.'s "Analysis of Airport Networks in Pakistan Utilizing [a] Complex Network Approach," and Sugishita K.'s "Dynamics of the US Domestic Airline Network During the COVID-19 Pandemic." Bagler's study focused on techniques for analyzing airport network connectivity, traffic dynamics, and risk reduction "with the help of studies that have been done on some of the airport networks." (Bagler G., 2008). Addressing threats in airport networks is difficult due to their complexity. One particular challenge is the requirement for effective coordination among airlines, airport security, and ground services. Outside events, like severe weather, disease outbreaks, or terrorist attacks, can also affect airport networks. This may restrict activities in the airport network and put passenger safety and security at risk.

I primarily looked at Bagler's study, which tried to figure out the network factors that affect how well airport networks function by looking at the ***characteristics of path length*** (L) and ***clustering coefficient*** (C) and suggesting ways to improve connectivity and lower risks. It was ideal how the author showed how complex airport networks are and how complex network analysis can be used as a model. Even though Bagler clearly thinks that the readers already know a lot about the topic, he did a good job of explaining the main ideas and terms used in the paper. In the beginning, I learned a bit about complex networks and got a general idea of nodes, links, and the idea of a weighted network. It was really helpful, too, that the author continued defining terms and parameters throughout the paper. Still, there were times when I needed to look things up elsewhere to understand what the author meant, mostly via references.

A preview of the paper

The airport network is a complex system based on the physical and logical topologies of the network's nodes and connections. The author highlights that performance can be defined by considering the overall efficiency of the network or the likelihood with which passengers can transit across the network. In the paper, there are five parameters and features discussed to measure the performance of the airport network, and they are as follows: the characteristic path length (L), the clustering coefficient (c), the closeness (L_i), the shortest path length, and the small world nature.

The characteristic path length is as followed:

$$L = \frac{1}{N(N-1)} \sum_{i,j=1,\, i \neq j}^{N} L_{ij},$$

where L_{ij} is the shortest path length between nodes i and j, and N is the total number of nodes in the airport network. In other words, L indicates the network compactness, and C measures the accessibility of the airport. The smaller L, the more compact and reachable the network. Consider the "Airport Network of India (ANI) (L = 2.2593), the Airport Network of China (ANC) (L = 2.067), the World-wide Airport Network (WAN) (L = 4.37), and the Italian Airport Network (IAN) (L = 1.98)." (Bagler G., pg. 2). As a result of its lower L value, the Italian airport is the most efficient. However, note that the worldwide airport network is much larger, with over 3,000 airports, whereas Italy has less than 100 airports.

A node's clustering coefficient is defined as the ratio of the number of links it has with its neighbors to the maximum number of links they might have had. And it is formatted as follows:

$$C = \frac{1}{N} \sum_{i=1}^{N} C_{i,}$$

The clustering coefficient evaluates network performance. It shows the average ratio of closed triangles in the airport network. A higher clustering coefficient corresponds to a more accessible and effective network. The ANC clustering coefficient is the highest at C = 0.733, indicating superior reachability. It's worth noting that IAN, with a measured c = 0.10, showed a clustering coefficient similar to a random model we have done in the class.

High clustering coefficients and small characteristic path lengths indicate a small-world network, but they do not fully assess network performance. Closeness (Li) is the average of the shortest paths between node 'i' and all other nodes. Closeness (Li) is a more accurate measure of network connectivity, as it calculates the average shortest paths between nodes. Lower node closeness means better network connectivity and performance. To visualize airport network performance, a plot of the frequency of flight routes against the shortest path length was provided, which can be found at the end. This shows the number of flight routes in the network for each shortest path length. A good network has a peak at shortest path length 2 and a thin tail between 4 and 5.

The author highlights the importance of network attributes such as betweenness and coefficient of assortativity and discusses how they affect the spread of diseases and network resilience. There were no formulas offered, though, as the author presumed that the reader understood the topic at hand. To learn more, I had to look into the references. The last section discusses how theoretical and computational studies might be used to design airports in the future. Further research revealed that the coefficient of assortativity (r), robustness (R_0), efficiency (E), and resilience(R_e)can be determined with the following formulas; refer to Freeman's paper for how betweenness is measured (and I won't go into detail):

$$r = \frac{\sum_{ij}(A_{ij}-k_i k_j/2M)k_i k_j}{\sum_{ij}(k_i \delta_{ij}-k_i k_j/2M)k_i k_j},$$

where A_{ij} is the adjacency matrix, and δ_{ij} is the Kronecker delta. If nodes with similar degree values tend to be connected to one another, the value of r becomes positive (assortativity). If nodes with a higher degree are more likely to be connected to nodes with a lower degree, the value of r becomes negative (disassortativity). This attribute clearly describes degree-degree connectivity. It is defined as being between -1 and +1. If high degree, high degree links dominate it is between 0 and +1. When high degree, low degree links dominate, the coefficient of assortativity is between 0 and -1.

$$E = \frac{2}{N(N-1)} \sum_{1 \le i < i \le N} \frac{1}{L_{ij}},$$

$$R_0 = \frac{E_2}{E_0}; \quad R_e = \frac{\int_{t_1}^{t_3} E(t)dt}{(t_3-t_1)E_0},$$

The reciprocal of the shortest path length is the “efficiency” of individual paths. Refer to *Figure 2*, to see the schematic illustration of the definition of robustness and resilience.

Lastly, the ratio of the number of shortest paths through a node (k) to the total number of shortest paths in the network is known as the betweenness (Bk) of that node. The betweenness (Bk) traffic centrality score of an airport does not always match its degree, which indicates the quantity of airport connections. By using betweenness as a criterion, airports with high traffic centrality can effectively locate their facilities, improving traffic dynamics.

My overview

The study uses cases from real life to show how the Double Pareto Law works in the Italian Airport Network and how WAN works in an assortative manner. These real-life cases put the theory into context and help us understand airport networks better. The paper talks about how hard it is to analyze airport networks, especially when you have to balance the need to stop the spread of disease with the chance of messing up the network. This makes the discussion more interesting by showing how hard it is to make decisions when building resilient airport networks.

I think there could have been more explanations, especially in the parts that talked about risks on airport networks. More thorough examples or simulations could have further helped me understand how the ideas being discussed could be used in real life. Adding more visual aids like network diagrams or simulation results could've really helped explain difficult ideas. The paper talks about a few different risks, but it would have been effective if it went into more detail about certain risks and how they might affect airport networks. This might include using case studies or historical examples to show how the risks noted have actually happened in the real world.

The study adds a lot to our knowledge of airport network performance and risks by using complex network analysis. Its best features are the thorough risk assessment, the clear definitions of network parameters, and the use of theoretical ideas in the real world. By working on the suggested improvements, the paper could become easier to find and have a bigger effect, making it a more useful tool for both academic and practical individuals studying airport networks.

Figures

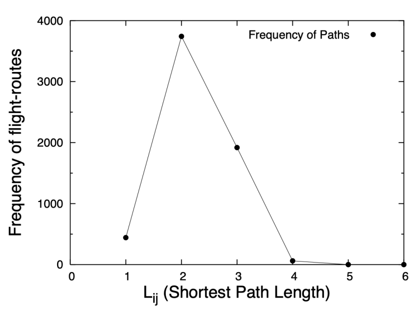

Figure 1: Shortest path distribution in Airport Network of India (ANI). The ANI comprises of 79 airports and 449 one-way flight routes. The network is put together by 11 airlines, largely domestic and a few international.

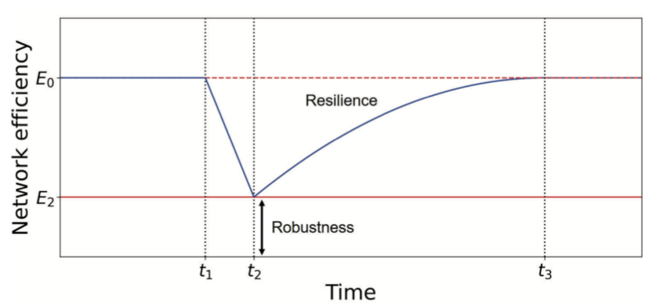

Figure 2: Schematic illustration of the definition of robustness and resilience.

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