Proceedings of the 3rd International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/5/20230675

The comparison of Chinese and Australian aviation networks under the most important node attacks

Aiwen Zhang

University of New South Wales, NSW, Australia

aiwen.zhang1@student.unsw.edu.au

Abstract. Air traffic plays an important role in the economy and daily life both in developing and developed countries, The shutdown of the crucial airport will lead to large financial losses. In this study, the data have been collected from Openflight.org with information of flights and routes. Then the characteristics of the Chinese aviation network and Australian aviation network have been computed. The results indicate that the Chinese aviation network and Australian aviation network are both scale-free networks of power-law degree distribution with long-tail attributes. Then, the centrality analysis of the top 10 airports in the Chinese aviation network and Australian aviation network have been assessed, such as betweenness centrality analysis and closeness centrality analysis. Lastly, the study looks into how the characteristics of the Chinese and American aviation networks have changed as a result of node attacks and offers helpful advice for both the Chinese and Australian aviation networks after the most important node attacks.

Keywords: Chinese Aviation Network, Australian Aviation Network, Network Characteristics, Centrality Analysis, Important Node Attacks.

1. Introduction

Air traffic is a vital part of intermodal transportation in both developing and industrialized nations, and it has a significant impact on both the global economy and daily life. This research is going to study aviation networks in developing country's China and developed country's Australia. It is estimated that China's airline business and supply chain contribute $78 billion to the country's GDP. [1] Australia's GDP is estimated to be increased by the air transport industry, which includes airlines and their supply chain, by $39 billion in US dollars. [2] Air transportation systems can be affected by extreme weather conditions or terrorist acts, which can lead to large financial losses. For several weeks, the Rockhampton Airport was closed as a result of the 2011 Queensland floods. [3] Therefore, some questions should be considered, including how the Chinese and Australian aviation networks will function, and how the characteristics of communities will change if a single node is attacked, and the network's most important airport is shut down.

2. Methodology

2.1. Dataset

For this research, the data is obtained from Openflight.org [4]. The dataset provides the details of airports and routes.

DOI: 10.54254/2755-2721/5/20230675

2.2. Network generation

From the dataset, all airports and routes can be filtered out by using Python pandas. The network can be generated using Python Networkx. After pre-processing the data, there are 236 nodes representing the airports in the Chinese aviation network and 2699 edges showing the routes between them. There are 113 nodes and 441 edges in the Australian aviation network, respectively. An airport is represented by each node in the network graph, and a route between two airports is represented by a directed edge. The airport's latitude and longitude data will be used to form the Chinese aviation network geographically by using Gephi.

3. Results

3.1. Network characteristics

3.1.1. Network degree distribution. The degree distribution describes the probabilities that different degrees will be present in a node. In this equation, the P(k) is cumulative degree distribution, n represents the number of city nodes, and one single node has k routes. The following equation is for the degree distribution[5]:

$$\mathrm{P(k)} = \sum_{k'=k}^{N} p(k') \quad (1)$$

Figure 1 and Figure 2 present the degree distribution with original coordinates and logarithmic coordinates of the Chinese aviation network. Figure 3 and Figure4 present the degree distribution with original coordinates and logarithmic coordinates Australian aviation network. To determine the degree distribution and whether the Chinese aviation network and Australian aviation network are power-law networks, we use the original coordinates as well as double logarithmic coordinates. Figure 2 and Figure 4 show the Chinese aviation network and Australian aviation network both have power-law characteristics with a "long tail" attribute. According to calculations, the power-law exponents of the Chinese and Australian aviation networks are respectively -0.77 and -1.07. Therefore, Both the Chinese aviation network and Australian aviation network are scale-free networks [6][7].

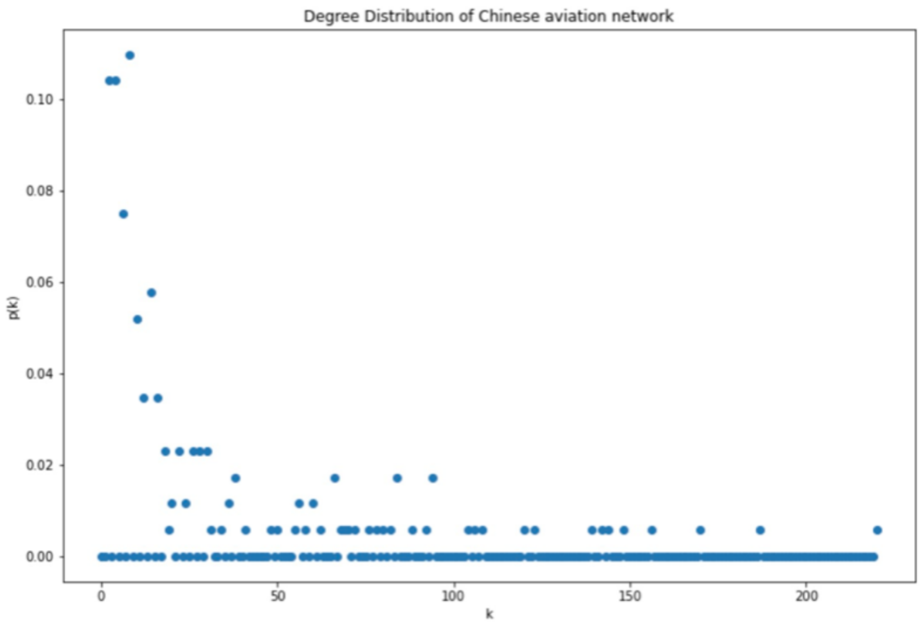

Figure 1. Degree Distribution with Original Coordinates of Chinese aviation network(Photo credit: Original).

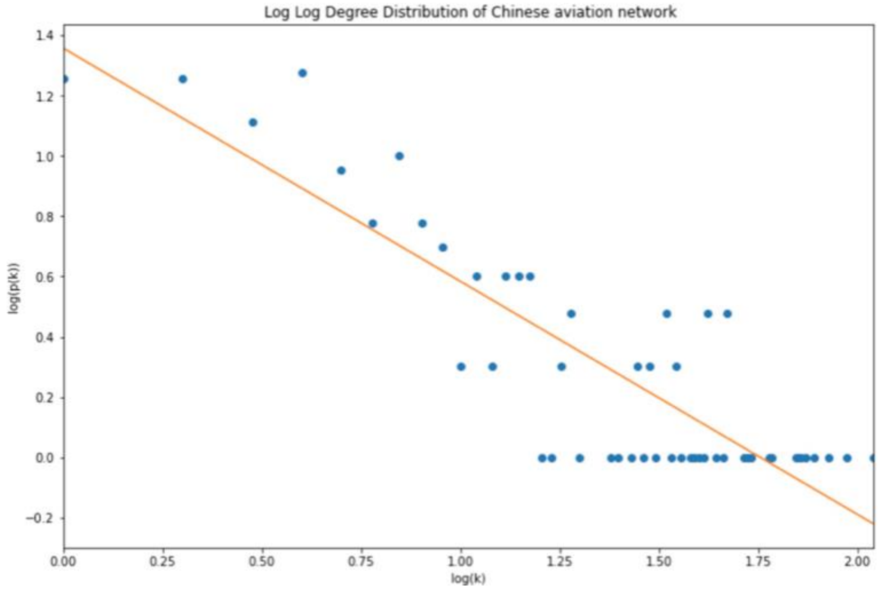

Figure 2. Degree Distribution with Logarithmic Coordinates of Chinese aviation network Log (pk) ≈-0.77log(k). (Photo credit: Original).

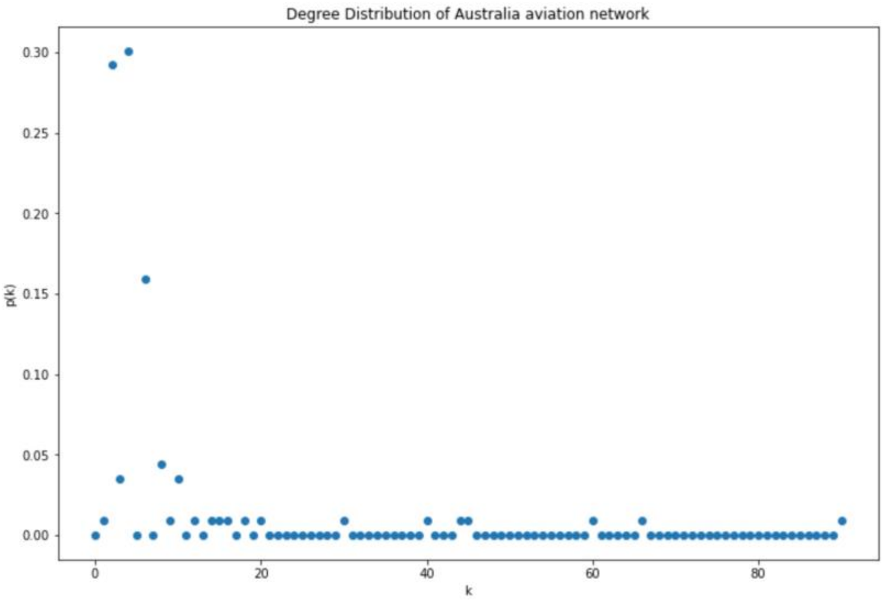

Figure 3. Degree Distribution with Original Coordinates of Australian aviation network.(Photo credit: Original).

DOI: 10.54254/2755-2721/5/20230675

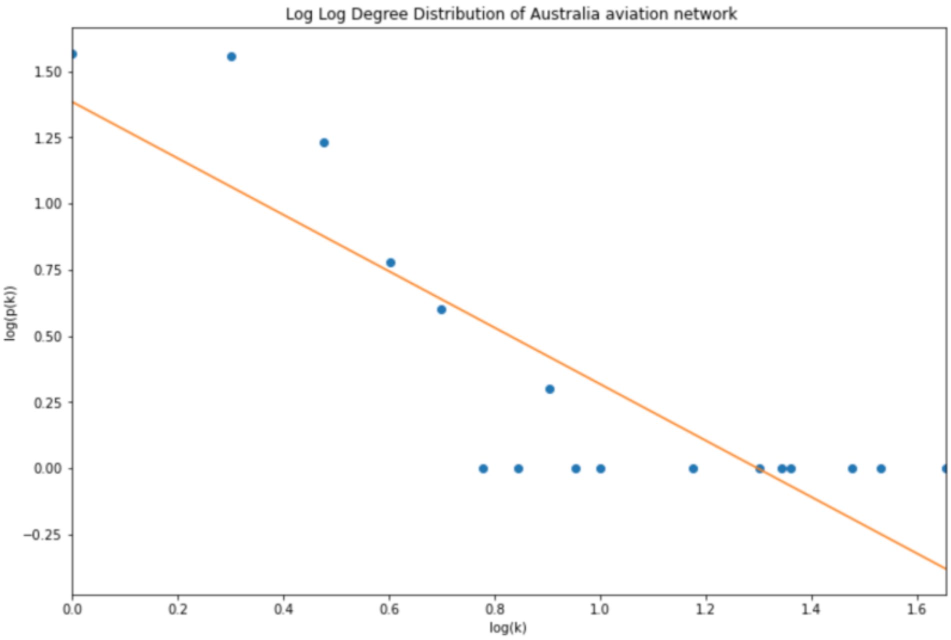

Figure 4. Degree Distribution with Logarithmic Coordinates of Australian aviation network Log (pk) ≈-1.07log(k). (Photo credit: Original).

3.1.2. Density. The network density is an important factor to take into account because it may show us how connected the network is. The equation will provide a total number of edges m divided by a total number of possible edges $\frac{n(n-1)}{2}$ because our graph is undirected, where n represents the total nodes. The density equation is as follows [8]:

$$D = \frac{m}{\frac{n(n-1)}{2}} \tag{2}$$

Rounding to two decimal places, the Australian aviation network density value is 0.03 and the Chinese aviation network density value is 0.09, respectively. Comparing such findings, it may be demonstrated that the aviation network of China is denser and more interconnected than Australia's.

3.1.3. Average shortest path length. The phrase "average path length," which measures the effectiveness of the Chinese aviation network, refers to the edge numbers between any two network nodes. The d_{ij} is the distance between two nodes in a network with labels i and label j that is determined by the edges on the shortest path between them. L stands for the abbreviation for average path length that can be calculated using the averaged mean distance between two nodes across all possible pairs. The equation is shown below:

$$L = \frac{1}{1/2N(N-1)} \sum_{i \geq j} d_{ij} \tag{3}$$

According to two decimal places of rounding, the shortest path length of the aviation network in China is approximately 2.19, and the result in the Australian aviation network is 2.93. Therefore, the results illustrate that the Chinese aviation network is more effective than the Australian aviation network.

3.1.4. Clustering coefficient. The clustering coefficient, which assesses how well nodes in a graph tend to group, can be used to gauge how cohesive the Chinese aviation network is. The average clustering coefficient will be looked at in this study.
Assume that a network node i has k_i edges that connect it to k_i other nodes. All of these nodes are node i's neighbours. These edges can have $k_i(k_i - 1)/2$ potential edges in total. Assume that these k_i nodes

genuinely have E_i edges connecting them. The equation for the mean clustering coefficient is as follows [9]:

$$C_i = \frac{E_i}{k_i(k_i-1)/2} \tag{4}$$

Chinese aviation network's average clustering coefficient, rounded to two decimal places, is found to be 0.66, and the Australian aviation network's average clustering coefficient, rounded to two decimal places, is 0.46. From the results, the Chinese aviation network is more clustered than the Australian aviation network.

3.2. Network Centrality Analysis

3.2.1. Betweenness Centrality. Betweenness centrality $C_B(i)$ is a control index that shows the measure of a single node city which becomes the intermediary of passenger flow linkage between other node cities. The quantity of shortest routes between nodes i and j is N_{jl}, while the number of pathways that pass via node i is N_{jl} (i).The following is the betweenness centrality equation:

$$C_B(\mathrm{i}) = \frac{2\sum_{j\neq i\neq N} N_{jl}(i)/N_{jl}}{(n-1)(n-2)} \tag{5}$$

3.2.2. Closeness centrality. The closeness centrality can be calculated using the total distance of the shortest path that links the node to every node in the network. The network's shortest path between Ni node as well as other nodes, which is used to determine the closeness centrality C(i), and where the d in the subsequent equation denotes the separation between nodes j and I, indicates the accessibility of the network's Ni node. The closeness centrality equation is shown below [10]:

$$C(i)=\frac{(N-1)}{\sum_{j\neq i}^{n} d_{ij}} \tag{6}$$

Table 1. The top 10 Airports of the Chinese aviation network in Degree, Betweenness centrality, and Closeness centrality.

Airport	Degree	Airport	Betweenness centrality	Airport	Closeness centrality
Beijing Capital International Airport	220	Beijing Capital International Airport	0.18	Beijing Capital International Airport	0.73
Guangzhou Baiyun International Airport	187	Chengdu Shuangliu International Airport	0.12	Guangzhou Baiyun International Airport	0.68
Chengdu Shuangliu International Airport	170	ÜrümqiDiwopu International Airport	0.09	Chengdu Shuangliu International Airport	0.66
Xi'an Xianyang International Airport	156	Guangzhou Baiyun International Airport	0.09	Xi'an Xianyang International Airport	0.64
Chongqing Jiangbei International Airport	148	Xi'an Xianyang International Airport	0.08	Chongqing Jiangbei International Airport	0.63

Table 1. (continue)

Airport	Degree	Airport	Betweenness centrality	Airport	Closeness centrality
Shenzhen Bao'an International Airport	144	Kunming Changshui International Airport	0.07	Shenzhen Bao'an International Airport	0.63
Kunming Changshui International Airport	142	Chongqing Jiangbei International Airport	0.05	Shanghai Pudong International Airport	0.62
Shanghai Pudong International Airport	139	Shanghai Pudong International Airport	0.05	Kunming Changshui International Airport	0.60
Shanghai Hongqiao International Airport	123	Taiping Airport	0.05	Changsha Huanghua International Airport	0.60
Changsha Huanghua International Airport	120	Shenzhen Bao'an International Airport	0.04	Shanghai Hongqiao International Airport	0.59

Table 1 illustrates the results of the top ten Airports in the Chinese aviation network in Degree, Betweenness centrality, and Closeness centrality. Table 1 lists the largest aviation bases in China, with degrees 220, 187, and 170 respectively, as Beijing Airport, Guangzhou Airport, and Chengdu Airport. The top three airports in terms of betweenness centrality are Beijing Airport, Chengdu Airport, and ÜrümqiDiwopu Airport, respectively, with values of 0.18, 0.12, and 0.09, making them significant hubs in the aviation network of China. Additionally, the closeness centrality of the top three airports is identical to the degree to which they are ranked, and with values of 0.73, 0.68, and 0.66, respectively, the top three airports in closeness centrality are the most convenient airports for passengers.

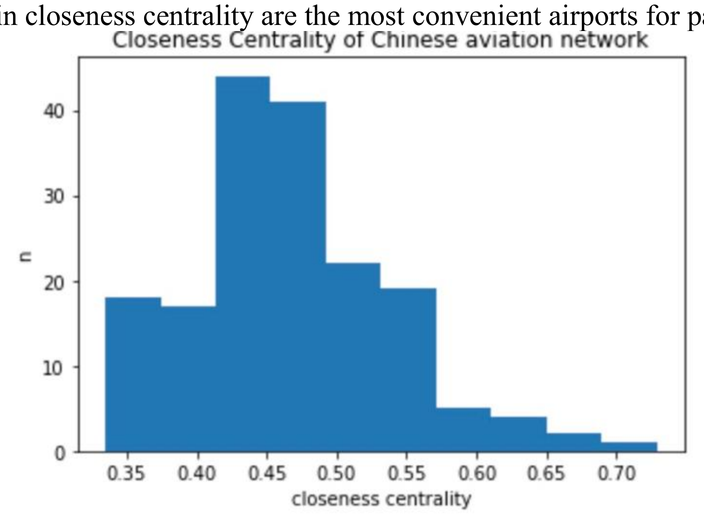

Figure 5. Closeness Centrality histogram of the Chinese aviation network. (Photo credit: Original).

Figure 5 shows the closeness centrality histogram of the Chinese aviation network, this histogram shows that the majority of airports that closeness centralities between 0.35 to 0.55.

DOI: 10.54254/2755-2721/5/20230675

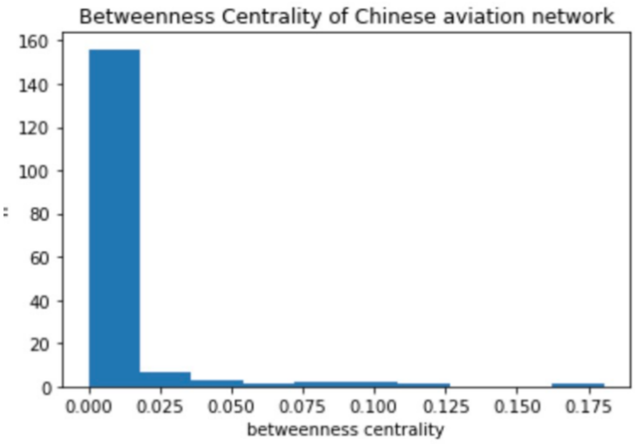

Figure 6. Betweenness Centrality histogram of the Chinese aviation network. (Photo credit: Original).

Figure 6 displays the Chinese aviation network's betweenness centrality histogram, which reveals that the majority of airports have betweenness centralities between 0 and 0.25.

Table 2. The top 10 Airports of the Australian aviation network in Degree, Betweenness centrality, and Closeness centrality.

Airport	Degree	Airport	Betweenness centrality	Airport	Closeness centrality
Sydney Kingsford Smith International Airport	90	Sydney Kingsford Smith International Airport	0.36	Sydney Kingsford Smith International Airport	0.54
Brisbane International Airport	66	Brisbane International Airport	0.28	Brisbane International Airport	0.54
Melbourne International Airport	60	Cairns International Airport	0.20	Melbourne International Airport	0.50
Cairns International Airport	45	Perth International Airport	0.17	Cairns International Airport	0.49
Perth International Airport	44	Adelaide International Airport	0.14	Darwin International Airport	0.49
Adelaide International Airport	40	Melbourne International Airport	0.13	Perth International Airport	0.48
Townsville Airport	20	Darwin International Airport	0.11	Alice Springs Airport	0.45
Mount Isa Airport	18	Toowoomba Airport	0.06	Townsville Airport	0.44
Alice Springs	16	Charleville Airport	0.04	Charleville Airport	0.42

DOI: 10.54254/2755-2721/5/20230675

Airport

Table 2 displays the results for the top ten airports in the Australian aviation network in terms of Degree and centrality of Betweenness and Closeness. Sydney Airport, Brisbane Airport, and Melbourne Airport are the three airports with the highest degrees, measuring 90, 66, and 60 respectively. Sydney Airport, Brisbane Airport, and Cairns Airport have the highest betweenness centrality values of the top three airports in the Australian aviation network. These airports, which serve as key transition hubs in the network, have betweenness centrality values of 0.36, 0.28, and 0.2. Airport of Sydney, Airport of Brisbane, and Melbourne Airport are the top three closeness centrality airports, with scores of 0.54, 0.54, and 0.5, respectively, in the Top Closeness Centrality ranking, which is the same as the degree ranking.

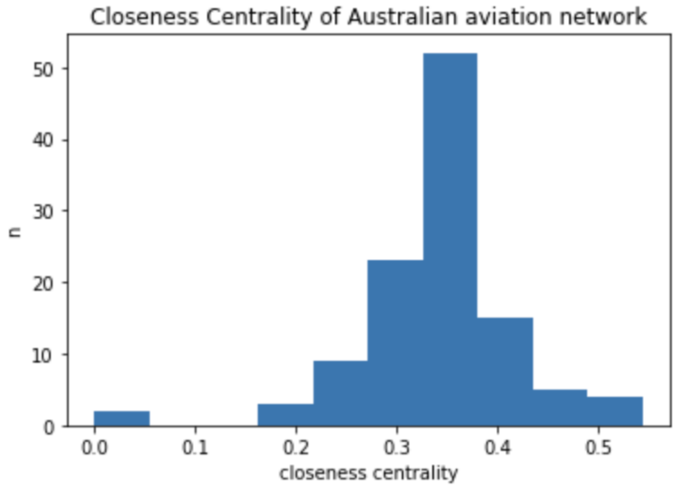

Figure 7. Closeness Centrality histogram of the Australian aviation network. (Photo credit: Original).

Figure 7 illustrates the closeness centrality histogram of the Australian aviation network. The graph shows that the majority of airports that closeness centralities between 0.2 and 0.4.

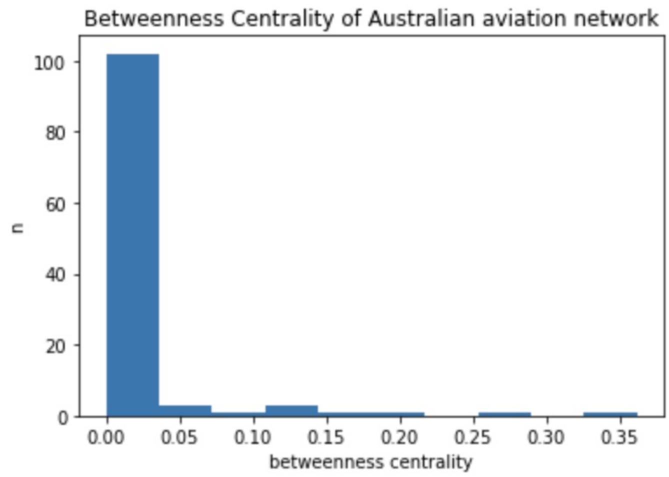

Figure 8. Betweenness Centrality histogram of the Australian aviation network. (Photo credit: Original).

Figure 8 shows the Australian aviation network's betweenness centrality histogram, which demonstrates that most airports have betweenness centralities between 0 and 0.5.

DOI: 10.54254/2755-2721/5/20230675

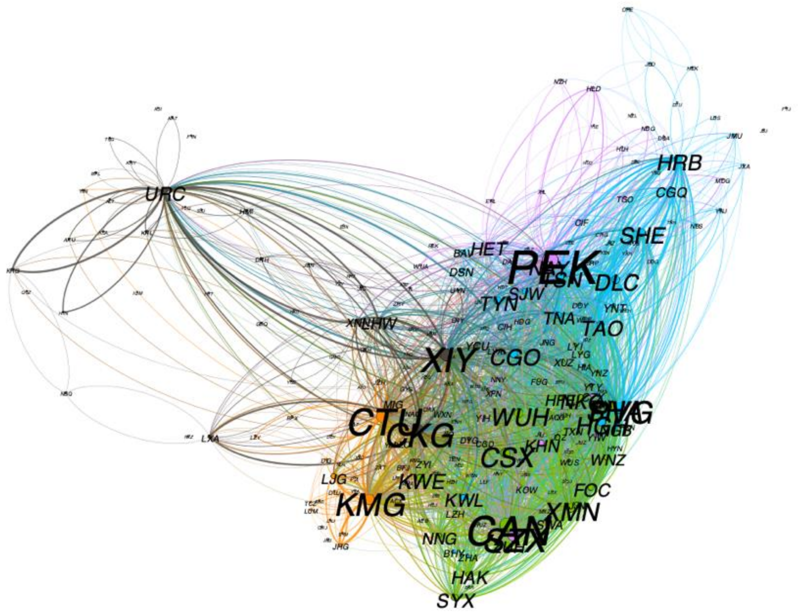

Figure 9. Chinese aviation network geographical graph by using Gephi (degree ranking). (Photo credit: Original).

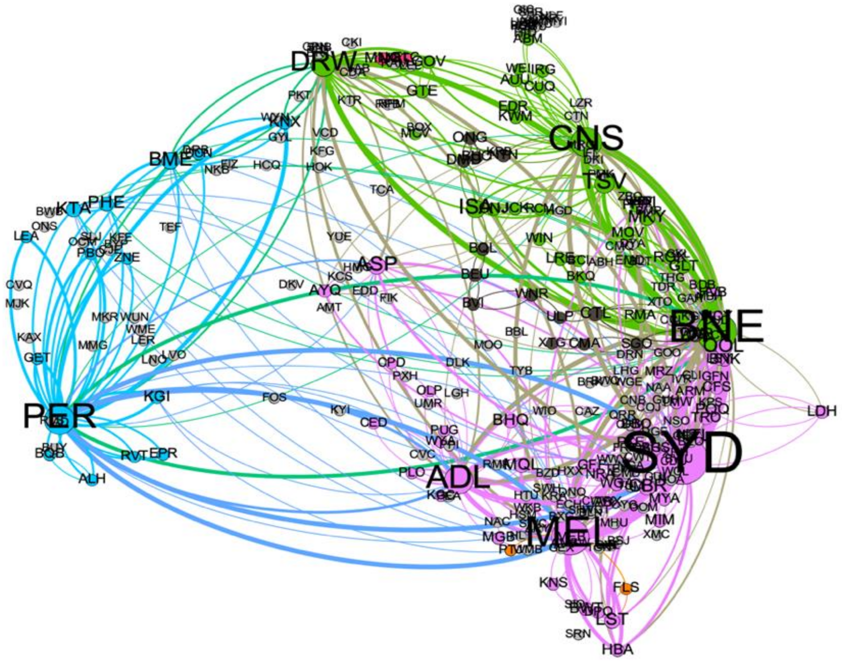

Figure 10. Australian aviation network geographical graph by using Gephi (degree ranking). (Photo credit: Original).

Figures 9 and 10 compare the geographic patterns of the Chinese and Australian aviation networks using the Gephi software with degree rankings. These two graphs show that Beijing Airport is the most important airport in China's aviation network, whereas Sydney Airport is the most important airport in Australia's aviation networks.

3.3. Important node attack analysis

In this analysis, the two most important nodes in the Chinese aviation network and the Australian aviation network that are Beijing Airport and Sydney Airport will be attacked and removed from those two aviation network.

Table 3. The Chinese aviation network characteristics value.

Number of nodes	Number of edges	Clustering coefficient	density	Average shortest path length
173	2755	0.66	0.092	2.19

Table 4. The Chinese aviation network characteristics value after deleting Beijing Capital International Airport.

Number of nodes	Number of edges	Clustering coefficient	density	Average shortest path length
172	2535	0.62	0.086	2.27

Beijing Capital International Airport is the most crucial airport despite of degree, betweenness centrality, and closeness centrality ranking. This airport has been removed from the Chinese aviation network by using python and Gephi and the 220 edges related to Beijing have been deleted. Therefore, the clustering coefficient value has decreased by 6% from 0.66 to 0.62. The density value has decreased by 7% from 0.092 to 0.086. The average shortest path length value has increased by 4% from 2.19 to 2.27. Therefore, From the important node attack simulation, if the Beijing Capital International Airport is attacked or shut down, the Chinese aviation network will be high impacted.

Table 5. The Australian aviation network characteristics value.

Number of nodes	Number of edges	Clustering coefficient	density	Average shortest path length
113	441	0.46	0.034	2.92

Table 6. The **Australian** aviation network characteristics value after deleting Sydney Kingsford Smith International Airport.

Number of nodes	Number of edges	Clustering coefficient	density	Average shortest path length
112	351	0.35	0.028	3.09

Sydney Airport is the most important airport in despite of degree, betweenness centrality, and closeness centrality ranking. 90 edges have been removed after Sydney Kingsford Smith International Airport shut down. Therefore, 20% percent of edges have been deleted, which is influential to the Australian aviation network. The clustering coefficient value has reduced 23 percent from 0.46 to 0.35. The density changed slightly, and the average shortest path length value increased 6 percent from 2.92 to 3.09.

According to those findings, attacking the most vital airport in the Chinese aviation network will have less of an impact than eliminating the most crucial airports in the Australian aviation network. After shutting down the Sydney Kingsford Smith International Airport, the network will be distributed, and less connected and passengers will transfer their flights through other cities to arrive at their destination.

DOI: 10.54254/2755-2721/5/20230675

4. Conclusion

In conclusion, the Chinese and Australian aviation networks are both small-world networks and feature power-law distribution with the "long tail" attribute. The crucial hub airports of the aviation network of China are the ÜrümqiDiwopu International Airport, Chengdu Shuangliu International Airport, Guangzhou Baiyun International Airport, and Beijing Capital International Airport. Important hub airports in the Australian aviation network include Sydney Kingsford Smith International Airport, Brisbane International Airport, Melbourne International Airport, and Cairns International Airport.

The two busiest airports in their networks, Beijing Capital International Airport and Sydney Kingsford Smith International Airport, were shut down as a result of our study of key node attacks. The Australian aviation network will be significantly impacted by the closure of Sydney Kingsford Smith International Airport. Based on these research results, compared to the aviation network of China, the aviation network of Australia is more dependent on hub airport nodes. Therefore, we must keep the hub airport operational and guarantee the stability of the entire network.

References

[1] IATA Economics. 2022. The importance of air transport to the People's republic of China.https://www.iata.org/en/iata-repository/publications/economic-reports/china--value-of-aviation/#:~:text=The%20air%20transport%20industry%2C%20including,totaling%20to%20US%20%24104%20billion.

[2] IATA Economics. 2022. The importance of air transport to Australia. https://www.iata.org/en/iata-repository/publications/economic-reports/australia--value-of-aviation/#:~:text=The%20air%20transport%20industry%2C%20including,totaling%20to%20US%20%2469%20billion.

[3] Air services. 2022. Impact of weather on operations. https://www.airservicesaustralia.com/about-us/our-services/how-air-traffic-control-works/impact-of-weather/open flights.org. 2022. Airport,airline and route data.https://openflights.org/data.html.

[4] Hongyong Wang and Ruiying Wen. Analysis of air traffic network of china. In 2012 24th Chinese Control and Decision Conference (CCDC), pages 2400–2403, 2012. http://www.matjazperc.com/publications/ChaosSolitonsFractals_112_97.pdf

[5] A. L. Barabasi, R. Albert, "Emergence of scaling in random networks", vol.286, Science, 1999, pp.509-512.

[6] R. Albert and A.-L. Barab´asi, Rev. Mode. Phys. 74 (2002) 47.bookdown,2022.density. https://bookdown.org/omarlizardo/_main/2-9-density.html

[7] J. He, Z. Liu, Y. Wu and S. Li, "Analysis of Aviation Networks Structure Based on Complex Networks Theory," 2012 Second International Conference on Instrumentation, Measurement, Computer, Communication and Control, 2012, pp. 179-182, doi: 10.1109/IMCCC.2012.49.

[8] Bingxue Qian & Ning Zhang, 2022. "Topology and Robustness of Weighted Air Transport Networks in Multi-Airport Region," Sustainability, MDPI, vol. 14(11), pages 1-15, June. https://ideas.repec.org/a/gam/jsusta/v14y2022i11p6832-d830847.html.