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**North American Airports and Complex Networks**

Course: Complex Network

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**Abstract:** Transportation infrastructure of a continent is one of the most important indicators of its economic growth. Lots of facilities are prepared by the government based on the importance of each airport. The links between airports are the main factor to calculate the importance of that airport. Therefore the relationship between countries can affect this importance. In this project, we will see the current structure of commercial airports in North America and calculate some complex network factors for each airports and then we will see what will happen if the commercial airport network will be disconnected between US and Canada.

In this project, we discovered the graph model of US and Canada Airport Network by using the available dataset1, then built an individual version of Airport Network of US and Airport Network of Canada separately.

Notice: all of the datasets are allocated to commercial airports (general airport).

**Connected Version of North America Data Set:**

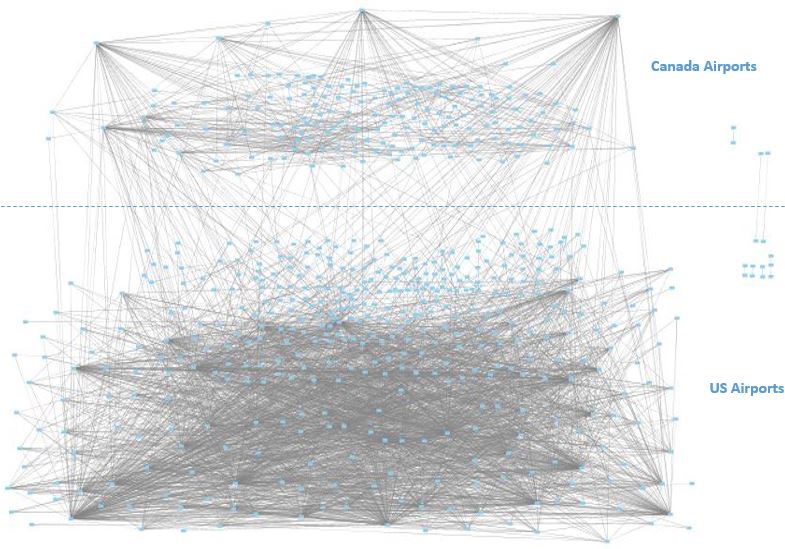
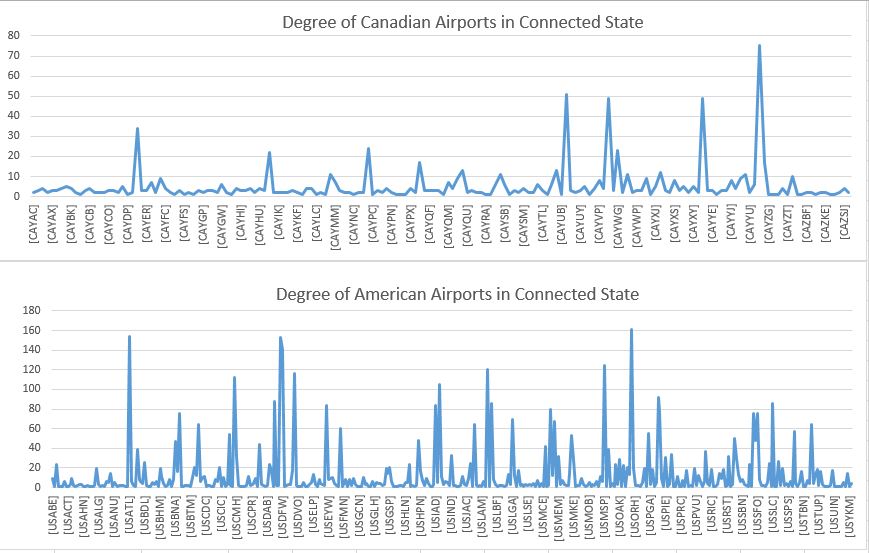


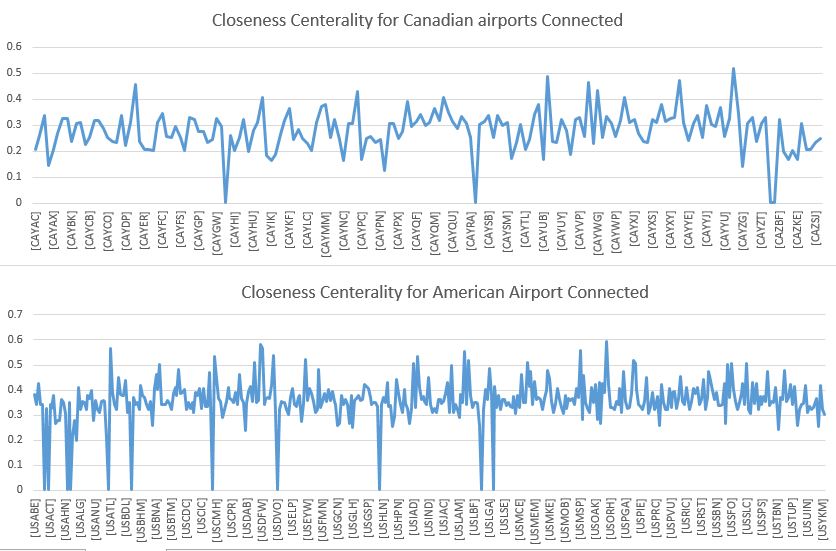
Figure1: North America Airport Graph

After we extracted the dataset. This graph contains 592 vertices and 3052 edges and 8 components which is shown in figure 1.The Density of this graph is 0.017446380390542828 and the average clustering coefficient is: 0.48204334679682737 and the average degree is 10.31081. There is one giant component and 7 small components which are so interesting because 2 of them. Their availability is strongly dependent on the connection between US and Canada [USDVO, CAZAM] [USLHW, CAYZY]. Moreover there are 5 components which are independent from other country. One independent component is available in Canada and 4 independent components in US. Graph 1 illustrates the degree distribution of each airport in US and Canada in connected state.



Graph 1: Degree Distribution of American and Canadian Airports in connected state

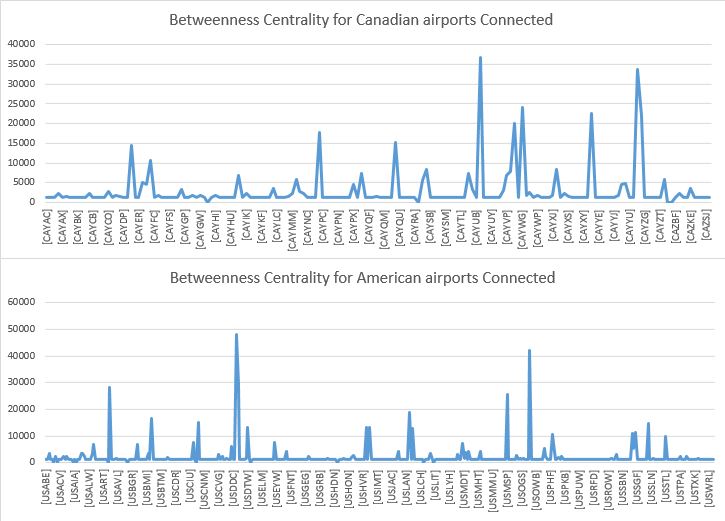
In the above graph USORD has highest degree with 161 edges in US. After that, there are 16 US airports with higher degree than the first highest Canadian airport CAYYZ with 75 edges. Meanwhile there are three airports in US with equal degree size of CAYYZ. After calculation the components and degree of every node. We find each node’s closeness centrality which is depicted on the next graph.



Graph2: Closeness Centrality of American and Canadian Airports in connected state

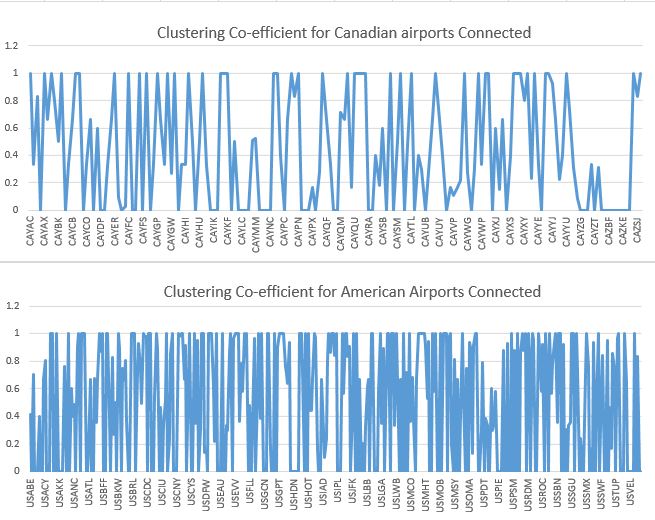
As far as our output depicted the USORD has the most closeness centrality with about 0.6 which is pretty high at all. Also, the most closeness airport is CAYYT with about 8 percent less than USORD in the 13th place in ranking.

On the next part, we calculated the betweenness centrality in this section for connected graph. It was amazing result based on previous two sections which is shown the USORD has the first rank but in this part USDEN passed USORD with over 48177. On the other hand, CAYUL has the highest betweenness among all of Canadian airports with 36660 and it stands on 3rd place. Graph 3 illustrates the Betweenness Centrality in connected graph.



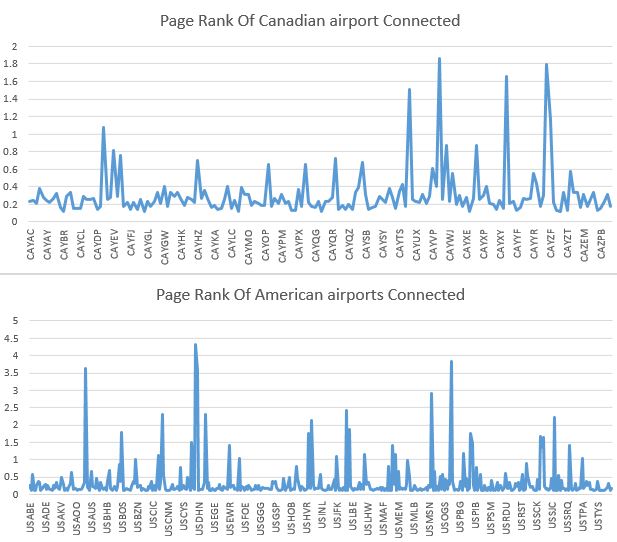
Graph3: Betweenness Centrality of American and Canadian Airports in connected state

Clustering Coefficient is the next factor for our project in this part. As it can see on the results there are about 200 nodes with 0 Clustering Coefficient and 150 nodes with 1 Clustering Coefficient. Which are depicted on Graph 4.



Graph 5: Clustering Coefficient of American and Canadian Airports in connected state

The last characteristics of the graph which we calculated in this section is the page rank of the graph which is shown in the Graph 6. In this part USDEN with 4.331499207 has the highest value and stands in the first place and the closest Canadian airport is CAYVR which is in the row of 12 with 1.866574987. In this level, it shows the highest American airport has the page rank more than two times of the CAYVR.



Graph 6: Page Rank Of Canadian airports Connected

**Disconnect The North America Airport Data Set:**

Now we assume that the whole of aviation economical communication between Canada and US disconnected so we delete some parts of figure 1, which is depicted on figure 2.

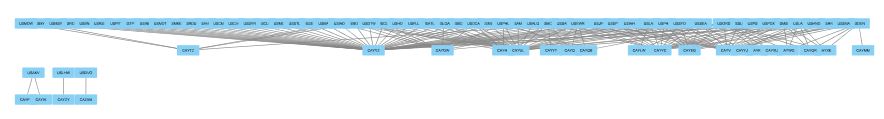


Figure 2: Edges which assumed deleted

In fact in this project, we will see how much this part of graph can effect on the airports characteristics. After we remove this part again we calculated the same network factors. This Critical part has 170 edges which connected 81 nodes. It has 4 components. In this deleted graph the most edges connected to CAYYZ with 46 nodes, After that CAYUL with 25 and CAYVR, CAYYC are next Canadian airports which affected and after all of them USORD stands in level 5. It can be predicted that most of Canadian airports affected by this deletion.

To show the division effect we prepared the following figure. In this Figure we could see some of general information about each graph.

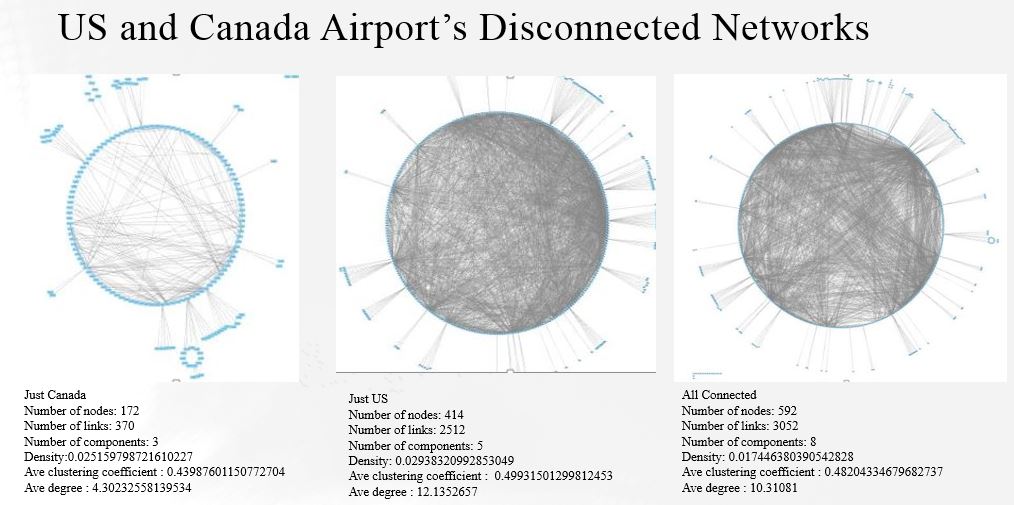
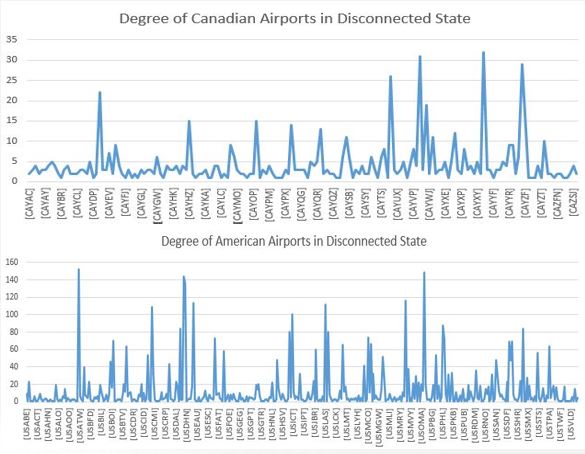


Figure 3: The connected and disconnected graph for North America Airport networks.

**Disconnected Version of North America Data Set:**

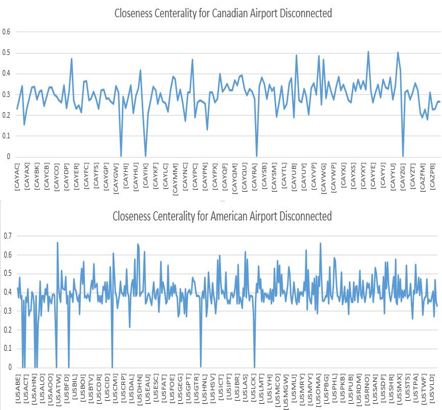
As the first division, we obtained the Distribution Degree for each country separately. Which is shown in the following graph.



Graph7: Degree Distribution of Canadian and American Airports in disconnected state.

As our dataset shows us, The USORD missed his first step and USATL Stands on the first place with the degree 152. In Canada the degree of the airports drops sharply to 32 for CAYYC as the highest degree.

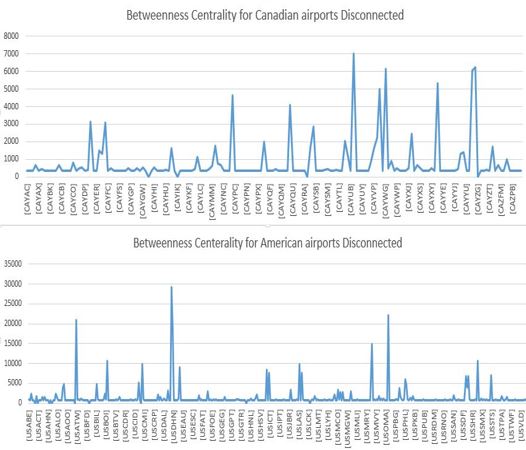
In the next part we calculated Closeness Centrality for this section which is illustrated on the Graph 8.



Graph8: Closeness Centrality of Canadian and American Airports in disconnected state.

In our data set we saw that the USATL with 0.663640032 has the highest Closeness Centrality in US and USORD and USDEN stand on the next steps, In Canada CAYYC has the highest Closeness Centrality with 0.50561125 and then CAYYZ has just about 0.003 less closeness in next step.

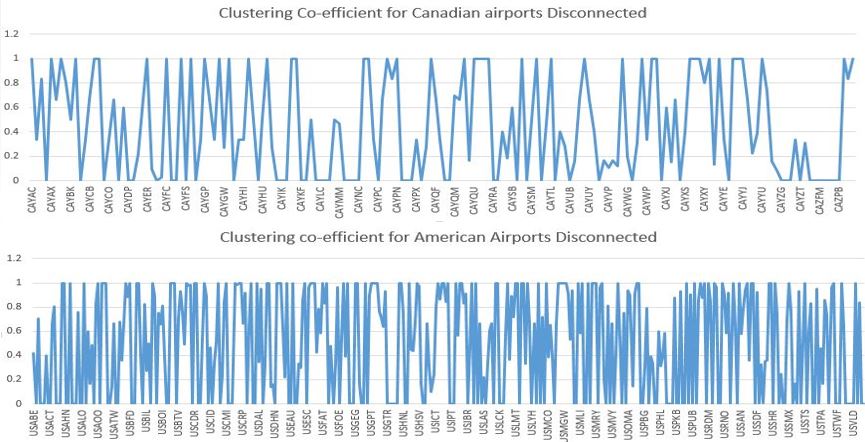
Betweenness Centrality is the next factor we calculated. The Output of our data is illustrated on Graph9.



Graph9: Betweenness Centrality of Canadian and American airports Disconnected state

The Betweenness Centrality is one of the factors which is affected The airports of both countries. Our Betweenness shows us in USDEN the Betweenness decrease to 29262.87307 which is almost 40% decreased in compare to connected state. Also, in CAYUL it reaches to 7022.245061 which is almost 1/5 of connected form.

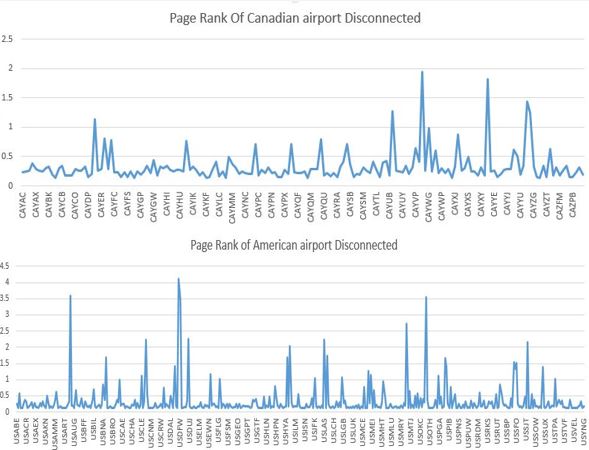
Clustering co-efficient is the next factor we calculated. The output of that shows in next graph.



Graph10: Clustering Co-efficient of Canadian and American Airports in Disconnected state.

US has 106 nodes with Clustering Co-efficient equal to 1 and 144 nodes with 0. Canada has 45 nodes with Clustering Co-efficient equal to 1 and 55 nodes with 0. To sum up totally they have around 200 nodes with 1 in Clustering Co-efficient and 100 nodes with 0. It can show us that the number of nodes with 1 co-efficient increased by 33% and the number of nodes with 0 co-efficient decreased to 50%.

The last part of the calculation is allocated to Page Rank. The page ranks which are shown in next graph can proof that this disconnection could not make a huge difference on the page ranks of airports.

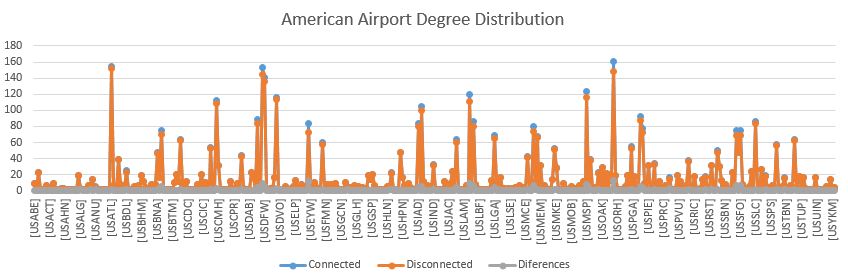
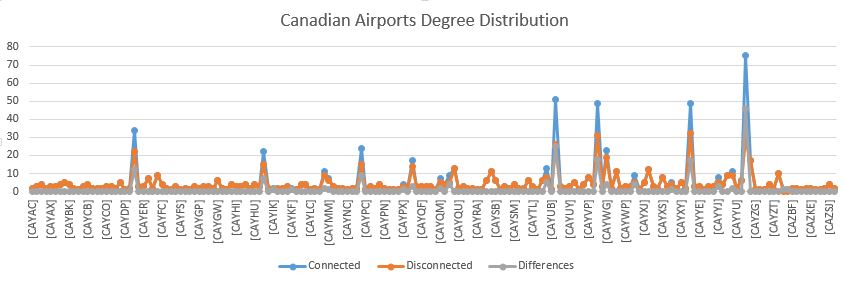


Graph 11: Page Rank of Canadian and American Airports in Disconnected state.

**Comparison of connected and disconnected airports graph:**

As it is shown in figure 3 there are some general information about differences between graphs. In this section, we will see graphically the differences and effect of removing figure2 from our general graph which is shown in figure 1.

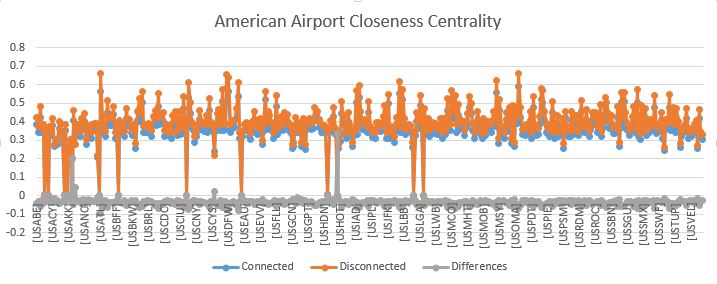
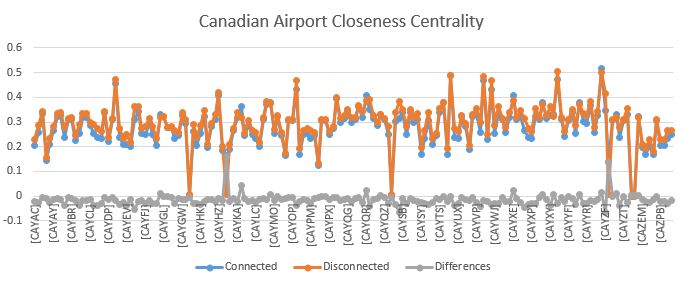
* Degree Distribution:



Graph 12: Degree Distribution Differences

In this Analysis, The highest Differences and Percentage of Differences allocated to CAYYZ with -61%. Meanwhile in US USORD has highest effect with -8%.

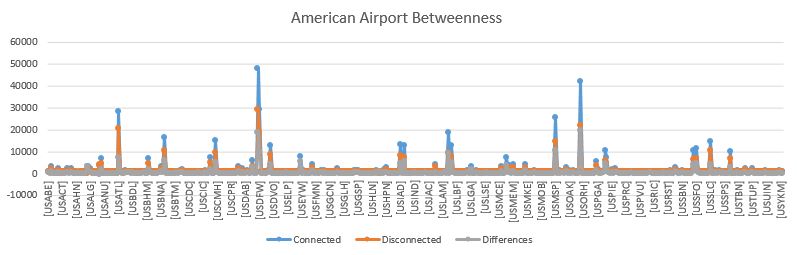
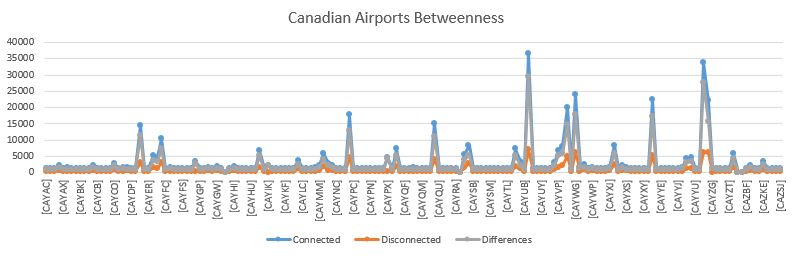
* Closeness



Graph 13: Closeness Centrality Differences

CAYIK and CAYZG loose most of their Closeness more than 90% of that is missed.

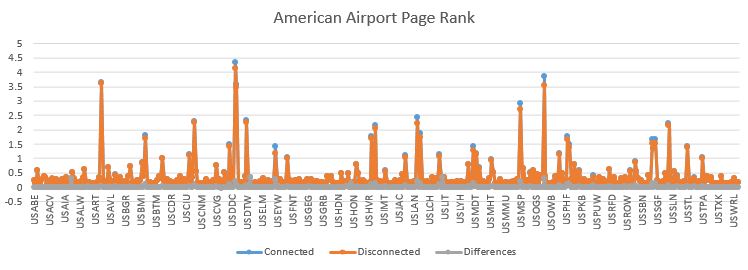
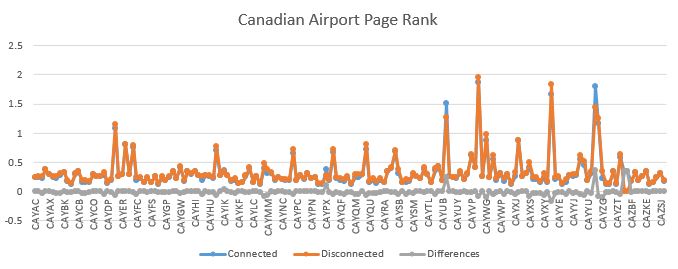
* Betweenness



Graph 14: Betweenness Centrality Differences

Interesting point of this part is allocated to CAYUL which loose more in betweenness value but CAYYZ loose more percentage of its Betweenness.

* Page Rank



Graph 15: Page Rank Differences

In this part the Page Rank Difference is not change very much. At most it changed by CAYYZ with less than 20%.

**Conclusion:**

In this project we found the most important Canadian and American airports Based on Closeness and Between Centrality, Degree and Page Rank.

* YYZ(Toronto), YVR(Vancouver) , YYC(Calgary), YUL(Montréal), YEG(Edmonton).
* ATL(Atlanta),ORD(Chicago), DEN(Denver), DFW(Dallas), MSP(Minnesota).

Moreover, we found US airline system is much more robust than CA airline system, based on the average clustering coefficient and density calculation.

On the other hand, we surveyed the effect of CA and US connection. We assume If the connection between US and CA disconnected:

* Canadian Airports will loose more edges (Degree Comparison).
* Closeness Centrality in Canadian Airports effected strongly.
* Betweenness Centrality in Canadian Airports effected strongly.
* The Page Rank of Airports are not affected hardly.
* 4 US airports and 2 CA airports could died at all. Such as USAKV, USHOG, USDVO, USLHW,CAYZY, CAZAM.

References:

1. https://openflights.org/data.html