Analysis of US Aviation Network

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ES 404 : Networks and Complex Systems

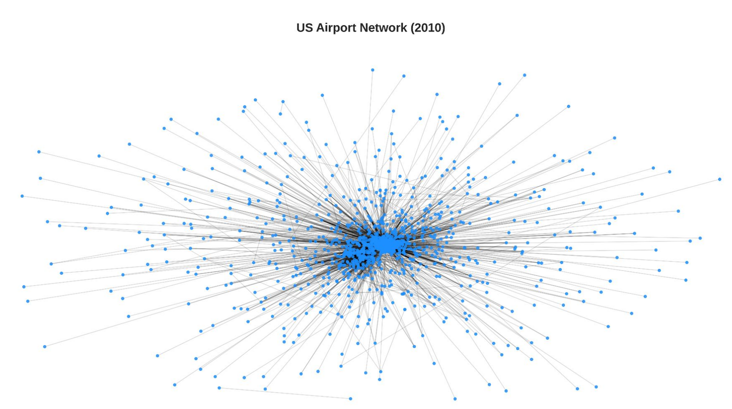
1. Introduction

The US Airport Network is a complex infrastructure system essential for domestic and international travel. We chose this Network because it is a real-world, large-scale transportation network. In this project, we analyze the 2010 U.S. airport network using network science tools to uncover complex connectivity patterns, central nodes, hubs, community structures and robustness. By analyzing these features, we gain insights into how well the system functions, identifies important hubs, and reveals patterns in connectivity. It highlights how efficiently people and goods move across the U.S. and reveals vulnerabilities like over-reliance on major hubs.

2. Network Overview

This is the directed network of flights between US airports in 2010. Each **node** in the network represents an individual airport in the United States. Each edge signifies a direct flight connection between two airports. The edges are typically weighted to indicate the volume or frequency of flights between these airports.
After cleaning and processing, It Consists of :

- **1574 Nodes (Airports).**
- **17,215 Edges (Routes).**



3. Research Questions

Q1. Which airports are the most important in terms of connectivity and influence?
Ans. We address this by calculating centrality measures like Eigenvector, Katz, Betweenness, Closeness, and HITS.

Q2. Does the network exhibit a power-law degree distribution, and what are its implications?
Ans. Yes, the network shows a heavy-tailed power-law degree distribution—most airports have few connections, while a few hubs have very high degrees, making the network robust to random failures but vulnerable to targeted attacks.

Q3. Does the airport network show any clear groupings or communities?
Ans. We use modularity and community detection algorithms (Louvain) to identify clusters of airports that are more interconnected.

Q4. Is the network assortative or disassortative? How do hubs interact?
Ans. The network is disassortative, meaning high-degree hubs tend to connect with low-degree regional airports, typical of a hub-and-spoke structure.

Q5. Is the network highly clustered or randomly structured?
Ans. We analyze global and local clustering coefficients to check if airports tend to form tightly connected local groups.

4. Datasets

We used publicly available datasets that represent real-world U.S. airport traffic in the year 2010. The datasets were originally compiled from the Bureau of Transportation Statistics (BTS) and later refined by Tore Opsahl.
Edge List – USairport_2010.txt:
Node Attributes – USairport_2010_codes.txt:

5. Methodology

We analyzed the 2010 U.S. airport network with 1,574 nodes (airports) and 17,215 edges (flight routes) using the following steps:

- Data Cleaning: Removed self-loops, cargo-only routes (zero weight), and duplicate edges. Summed weights for multiple flights on the same route.
- Network Construction: Built a weighted, undirected graph using Python's NetworkX library to represent the air traffic network.
- Centrality Analysis: Computed Degree, Eigenvector, Katz, Closeness, Betweenness, and HITS scores to identify key airports and their influence.
- Community Detection: Applied the Louvain method to detect regional airport clusters and calculated the modularity score.
- Assortativity & Clustering: Measured assortativity to assess hub–spoke behavior and calculated global/local clustering coefficients to analyze neighborhood density.

6. Results

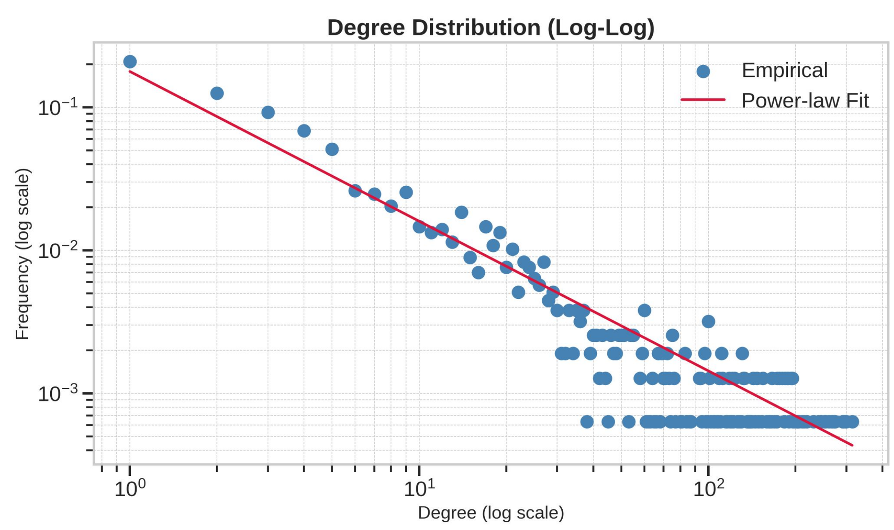


Fig a): Degree distribution

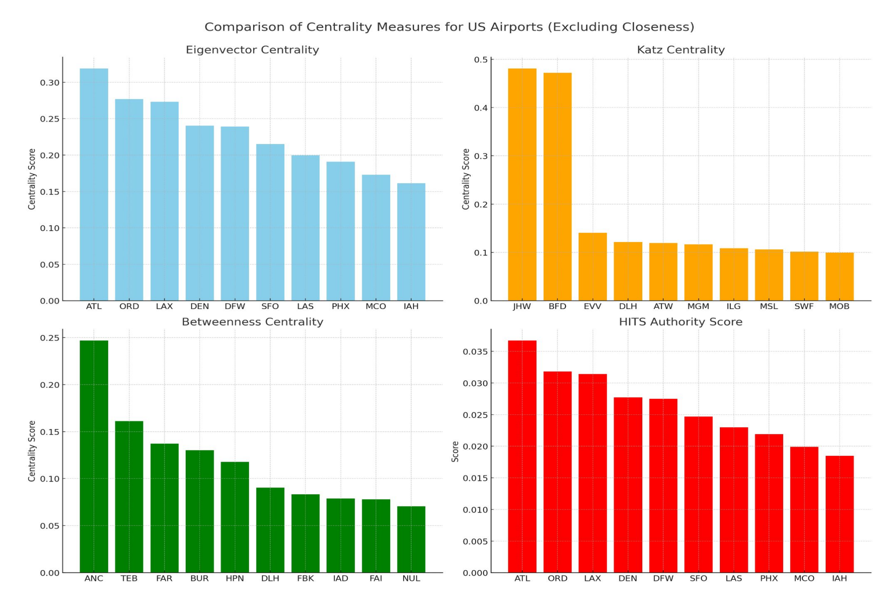


Fig b): Comparisons of Centrality Measures

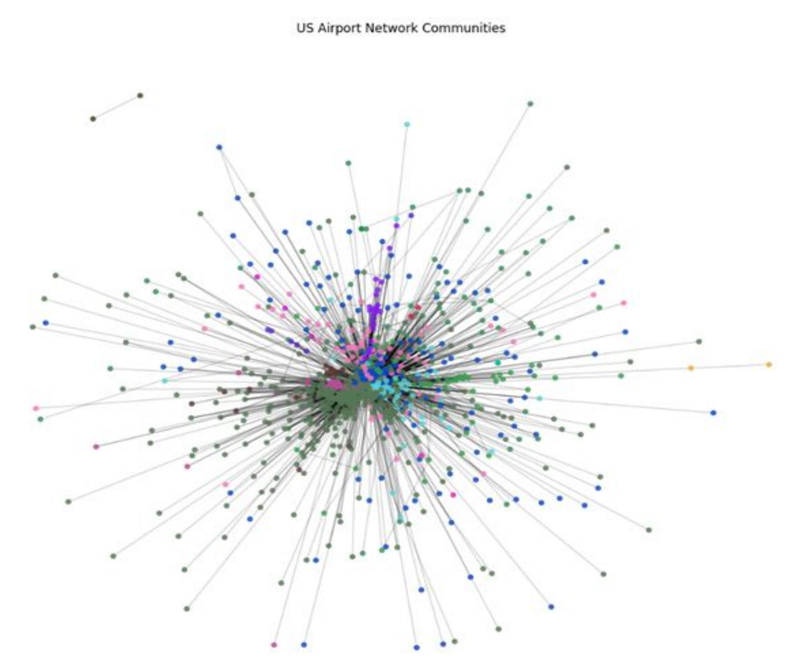


Fig c): US Airport Network Communities(Louvian method)

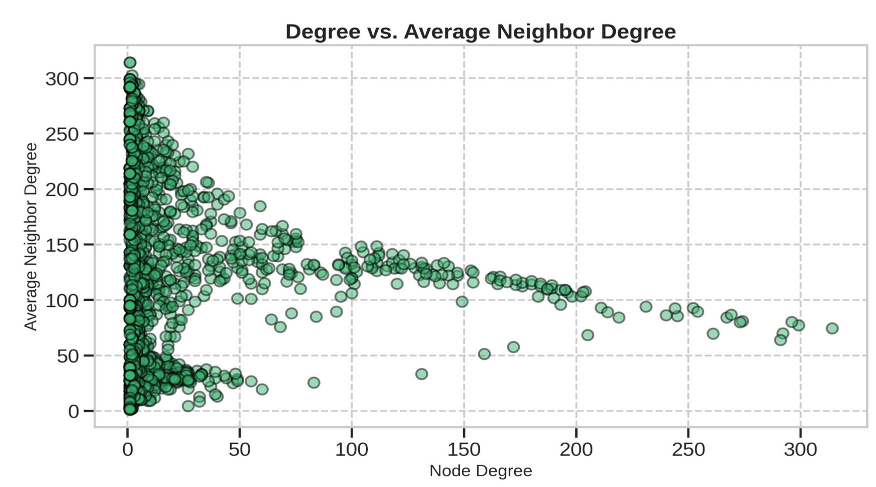


Fig d): Degree–Degree Correlation Plot

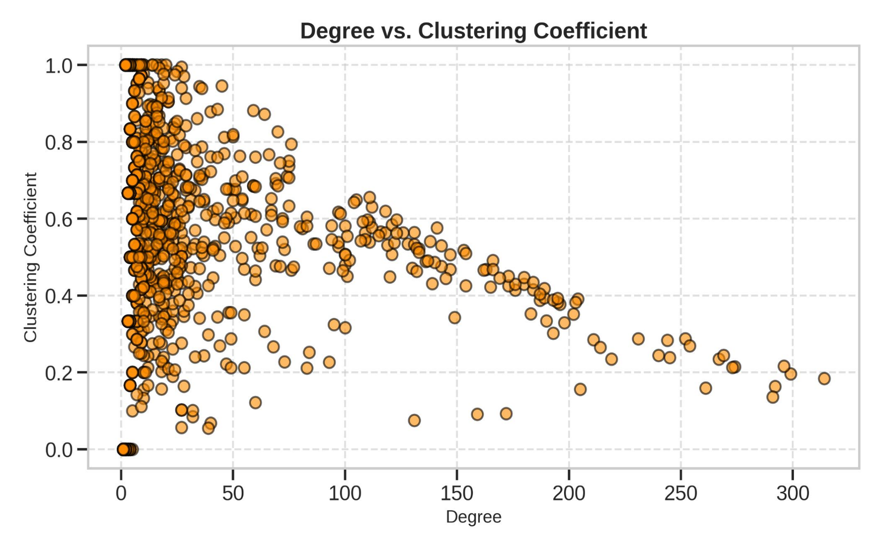


Fig e): Degree vs. Clustering Coefficient

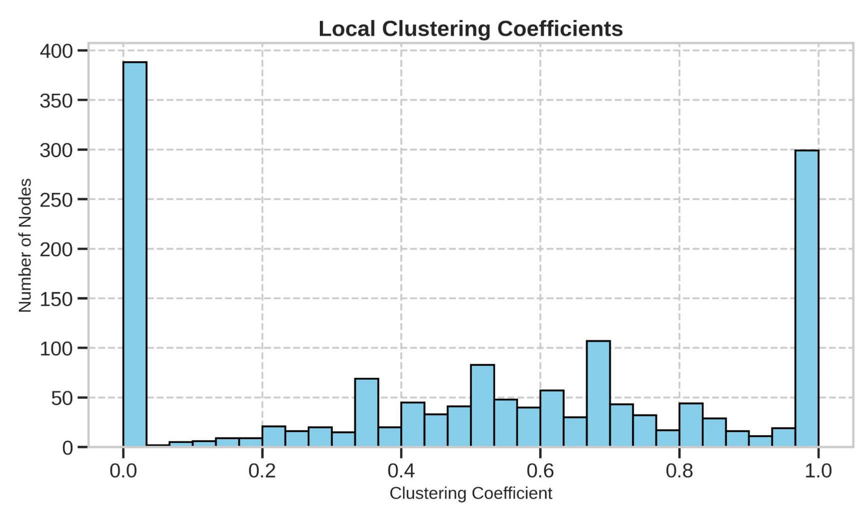


Fig f): Local Clustering Coefficients

7. Outcomes

Degree Distribution: The network shows a heavy-tailed (power-law) degree distribution, indicating that most airports have few connections, while a few hubs like ATL and ORD are highly connected.

Centrality Rankings: Major hubs (ATL, ORD, LAX, DEN, DFW) consistently rank high in Eigenvector, Closeness, and HITS centralities, confirming their importance in maintaining national connectivity.

Community Detection: Using the Louvain method, 20 communities were identified with a modularity score of 0.2541, indicating moderate clustering by region.

Assortativity: The network is disassortative (–0.1133), meaning high-degree hubs mostly connect to low-degree regional airports, consistent with hub-and-spoke systems.

Clustering Coefficient: Global clustering coefficient is 0.3841, much higher than a random graph, indicating strong local groupings among regional airports.

8. Conclusion

- The network follows a **power-law degree distribution**, confirming its **scale-free nature**, where a few hubs manage most of the traffic.
- **Central airports** such as ATL, ORD, and LAX emerged as key nodes based on multiple centrality measures — **critical for flow and connectivity**.
- **Community detection** revealed strong **regional clustering**, reflecting **airline alliances and geographic proximity**.
- **Disassortative mixing** was observed — **hubs tend to connect to smaller airports**, reinforcing the **hub-and-spoke architecture**.
- The **clustering coefficient decreases with degree**, showing that while small airports are locally connected, hubs act as **global bridges**.
- The network is **efficient but vulnerable** — random failures are tolerated, but **targeted attacks on major hubs could fragment** the system.

9. References

- Opsahl, T. (2010). US Airport Network Dataset. https://toreopsahl.com/datasets/#usairports
- Bureau of Transportation Statistics (BTS). Transtats Database.
- NetworkX Library Documentation: https://networkx.org/

10. Acknowledgement

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