# Analysing the Global Air Traffic Network: Risk Assessment at Different Spatial Scales

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## Introduction

Airline travel has become essential for economic development, tourism, and global connectivity, but is predicted to be experiencing exponential growth with 4.4 billion yearly passengers in 2018 and projections nearly doubling by 2040. Analyzing air travel through network perspectives, where airports are nodes and flight routes are edges, is a common and effective research approach and studies often focus on key airports and routes, utilizing different network-specific metrics and community detection algorithms to reveal connectivity and centrality within the global air travel network.

However, there is a limited analysis of the relationships between network measures and air travel demand across different spatial scales. This is especially relevant issue since recent research has highlighted the urgent need for understanding the robustness and vulnerability of the network, especially in events potentially requiring mass evacuations. This project aims to fill that gap by providing deeper insights into the spatial structure of the global air traffic network at different spatial scales, identifying most important communities and potential risk areas.

## Data & Methods

- OpenFlights Data - Airports, Routes & Airlines

The analysis focuses on commercial flights from 2014, using data from OpenFlights datasets. The dataset includes 7,698 airports with detailed identifiers and geographical information, as well as 67,663 routes among 3,321 airports operated by 548 airlines, including codeshare data.

- World Bank Data - Population & Economic Measures

The World Bank provides United Nations population data for 266 areas. The dataset also includes income group classifications based on GDP per capita, ranging from low to high income, and region labels, which help analyze air travel dynamics across different geographical areas.

- Passport Index Data - Visa Requirements

Passport Index data from January 2024 includes visa requirements for 199 world countries. The dataset categorizes visa requirements into no visa, e-visa, visa required, and no entry, with travel bans related to COVID-19 excluded for consistency.

Multi-scale Graph Creation Schema:

$G = (V, E, w)$ — Directed & Weighted

Weights $w(u, v)$: $1$ *if no visa*; $0$ *if visa*

Nodes: Airports or Countries

Edges $(u, v)$: $u$ - Source Airport; $v$ - Destination airport

The general analysis of the graph involved several methodologies to understand the structure and resilience of the air traffic network. Weighted degree centrality was used to identify the most connected nodes, highlighting airports or countries with the highest number of direct flight connections. PageRank assessed the relative importance of each node by considering the quality of its connections, pinpointing strategically important airports and countries. Community detection was performed using modularity maximization and Infomap algorithms to analyze whether communities form based on regions, revealing natural groupings of nodes. Additionally, a novel risk score metric was developed to assess the resilience of the air traffic network to local disruptive events at either country or world region level.

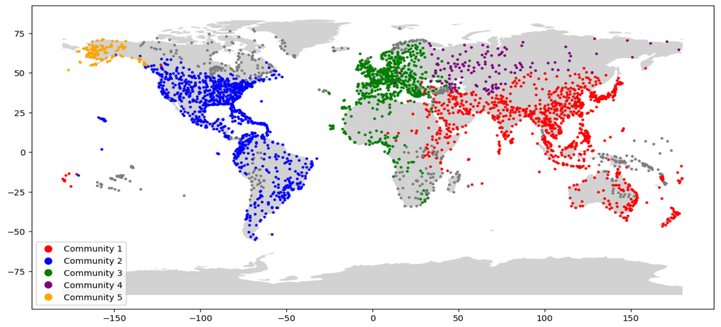
$$RS = \frac{(1 - ORPC_N) + (1 - A_N) + VR}{3} \cdot 100$$

$ORPC_N$- Outgoing Routes Per Capita norm.
$A_N$- Airports Per Country norm.
VR - Visa Restriction score (1 - Visa Liberty)

## Network Analysis

Degree and betweenness centrality calculations identified *Frankfurt Main* and *Charles de Gaulle* as the most central airports, with the top ten airports involved in 9.84% of all routes. Weighted degree centrality, factoring in visa restriction scores, highlighted *Denver International* as the most important node, but mainly due domestic connectivity. PageRank analysis found *Hartsfield-Jackson Atlanta*, *Atatürk*, and *Chicago O'Hare* to be the most influential airports.

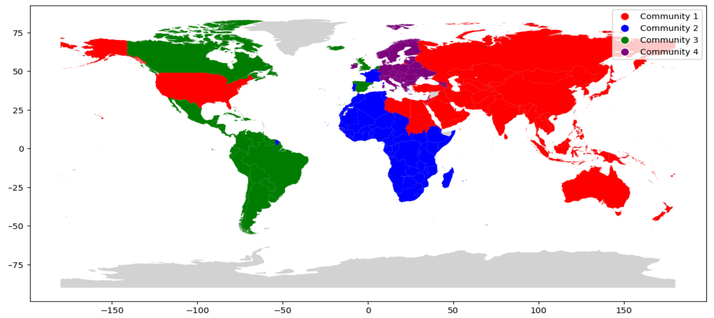
Community detection using greedy modularity maximization showed that airport communities often align with regional borders, with more shorter routes within regions like domestic flights in the United States. African airports depend on other regions for connectivity, while Russian and some former Soviet Union airports form a distinct community.




*Modularity maximisation airport communities. Five largest clusters colored.*

Country-level analysis identified *Germany* as the least restricted and *Afghanistan*, *Turkmenistan*, and *North Korea* as the most restricted for air travel. PageRank scores highlighted *France*, *Turkey*, and the *United Kingdom* as the most connected countries globally.

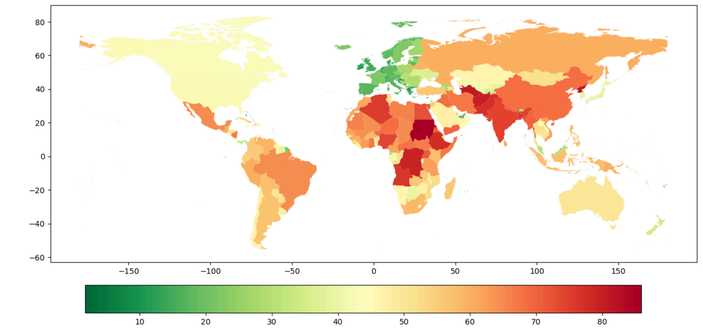
Community detection revealed distinct groupings: European countries often formed a single community, while larger Western European countries like *Great Britain* and *France* were grouped with overseas countries, emphasizing their role as interregional gateways. *The United States* was grouped with countries from Asia, Oceania, and parts of Northern Africa, showing different connectivity patterns compared to Europe.




*Modularity maximisation country communities.*

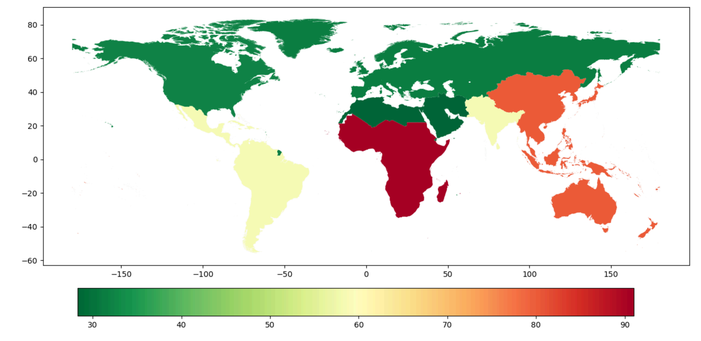
## Air Traffic Risk Score

The potential risk resilience of the air traffic network was assessed at country scale using a risk score based on outgoing routes per capita, airports per square kilometer, and visa restrictions. The analysis of 1102 airports and 18413 international flight routes revealed significant variability in risk scores. Unexpected high performers included Arabian Peninsula countries for outgoing routes, Caribbean countries for airport density, and Southern African countries for visa restrictions. Lower risk scores were common in Western Europe and former British colonies, while higher scores were found in Northern and Central Africa and Central Asia. Wealthier countries typically had lower risk scores, showing a strong positive correlation with income group labels.



*Risk scores of world countries.*

The potential risk resilience of the air traffic network was also assessed at the regional level, treating each region as a single entity. This analysis included 577 airports and 5788 interregional flight routes. Although the region-level assessment proved to be less effective with current approach than country-level analysis, it still provided valuable insights. Generally, regions in the northern hemisphere had lower risk scores due to lower population densities and better transport infrastructure. In contrast, southern hemisphere regions, with higher population densities and a greater proportion of low-income countries, had higher risk scores. Notably, Sub-Saharan Africa and the East Asia and Pacific region had particularly high risk scores.



*Risk scores of world regions.*

## Discussion & Conclusion

The project provided valuable insights into the spatial structure and resilience of the global air traffic network, identifying key airports and countries crucial for interregional connectivity and analyzing the network based on community detection. The analysis revealed significant variability in air traffic risk scores among countries and regions, highlighting both resilient and vulnerable areas. Risk scores tended to correlate with a country's economic wealth, though this does not imply causality. While the analysis was informative, the methodology has limitations and could be improved by incorporating additional parameters and balancing risk score calculations. Future research should refine these methods to better understand and enhance the network's robustness against potential disruptive events.