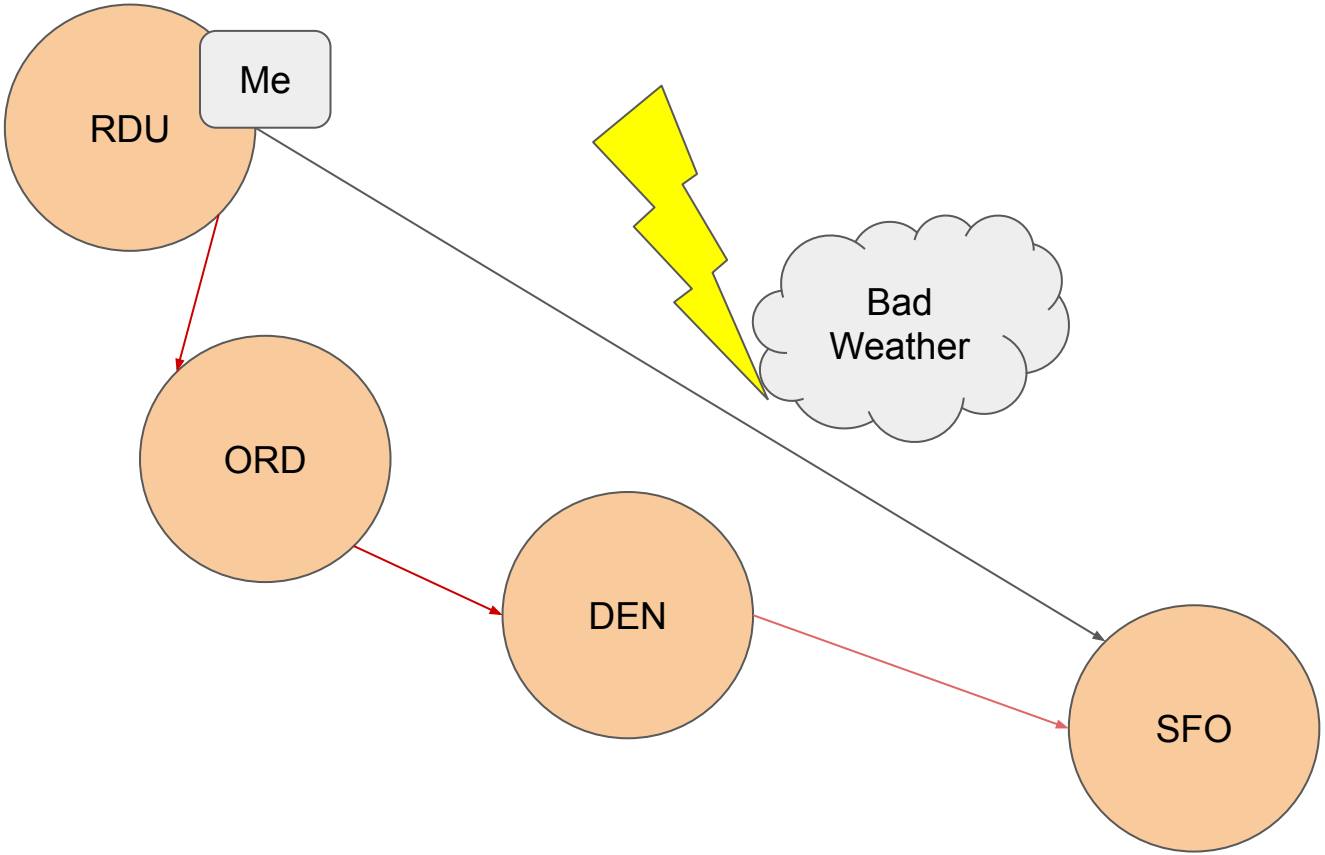
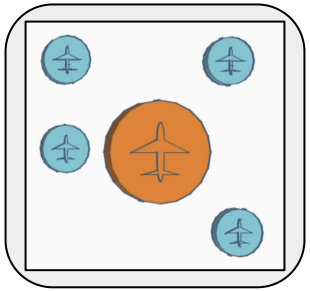

RDU
Me
Bad
Weather
ORD
DEN
SFO

Analyzing Resilience of Airlines Routes using Graph Computations

Nimaye Garodia, Alyssa Gorbaneva, Harsh Mathur

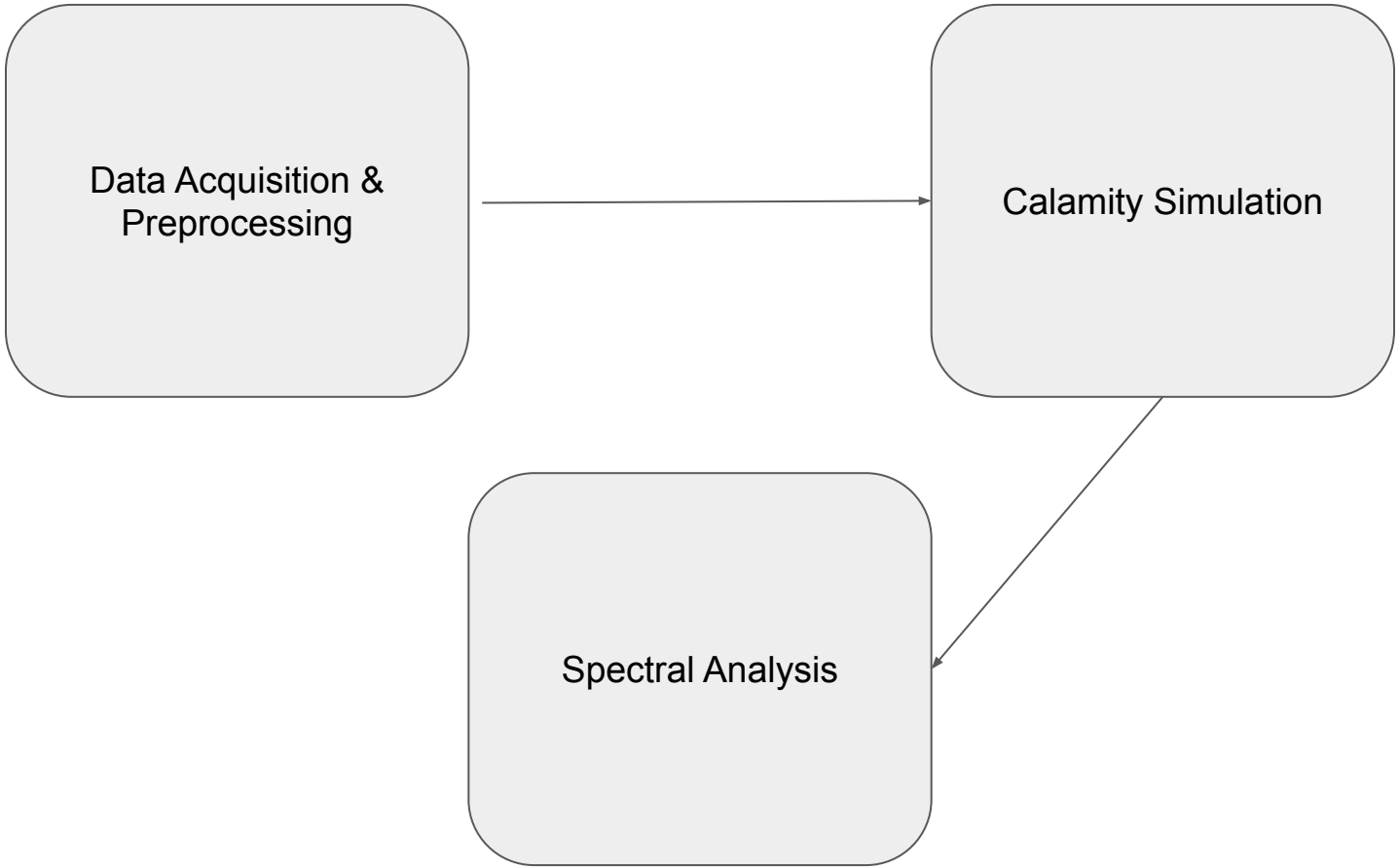


Our Promise

Find **major airline** that is most resilient to calamities and hub impact

Model calamities for airlines

Visualise Spectral Analysis of Airline Route Architecture


Data Acquisition &
Preprocessing
Calamity Simulation
Spectral Analysis

Definitions

Airline Codes: Unique identifiers assigned to airlines, typically using IATA or ICAO codes, representing the airline in the network.

UA = United, DL = Delta, AA = American

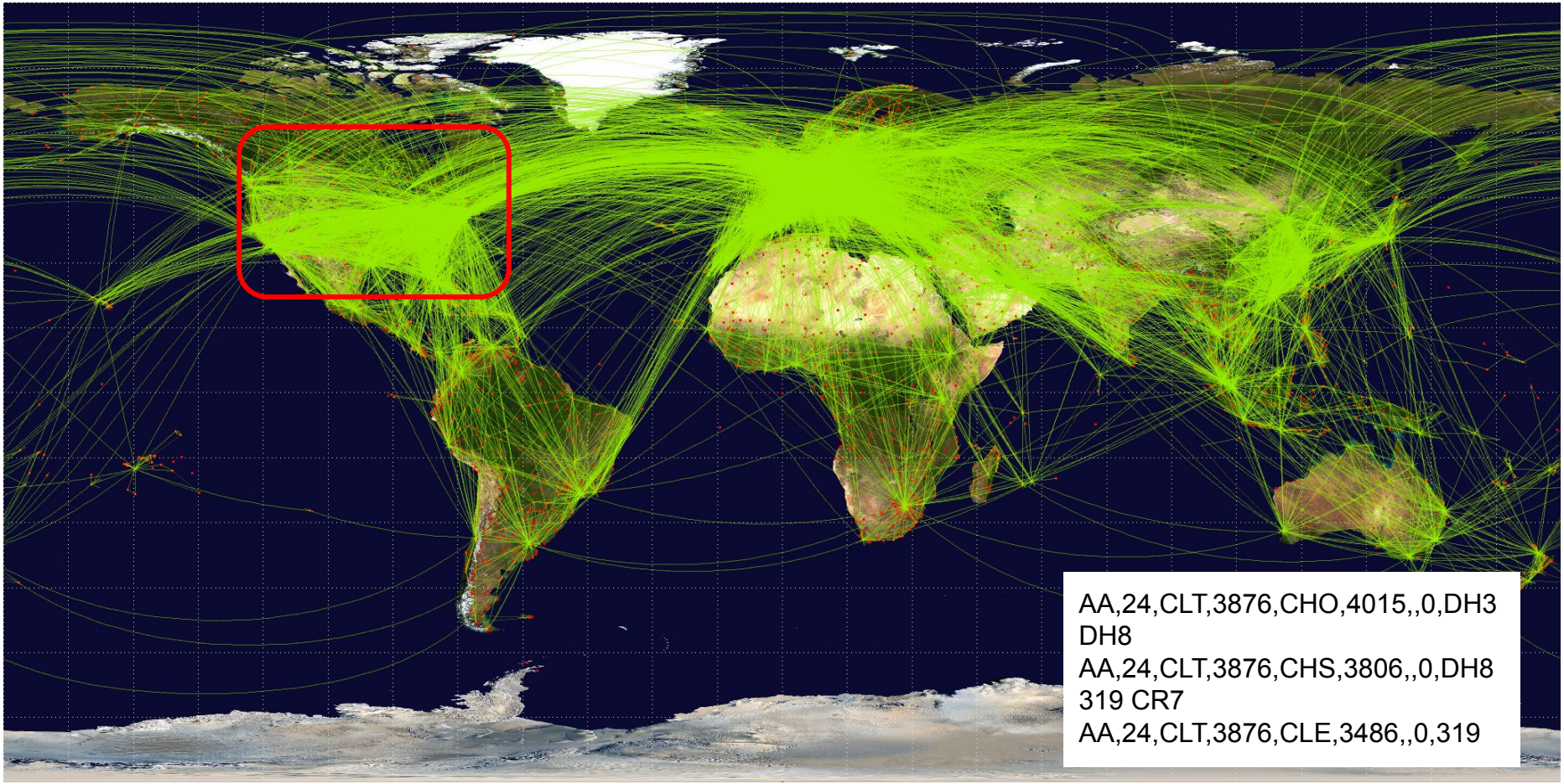
Airport Code: Unique 3 letter identifier for airport, used to index/label nodes in the graph

RDU = Raleigh-Durham International Airport

Hub (node): A central node in the airline network where multiple routes converge, facilitating transfers between flights. A special kind of **node**.

Destinations (node): Airports (nodes) that are the endpoints of routes, where flights from a hub or other airports arrive.

Routes (edge): Connections between airports in the airline network, representing the flight paths between them.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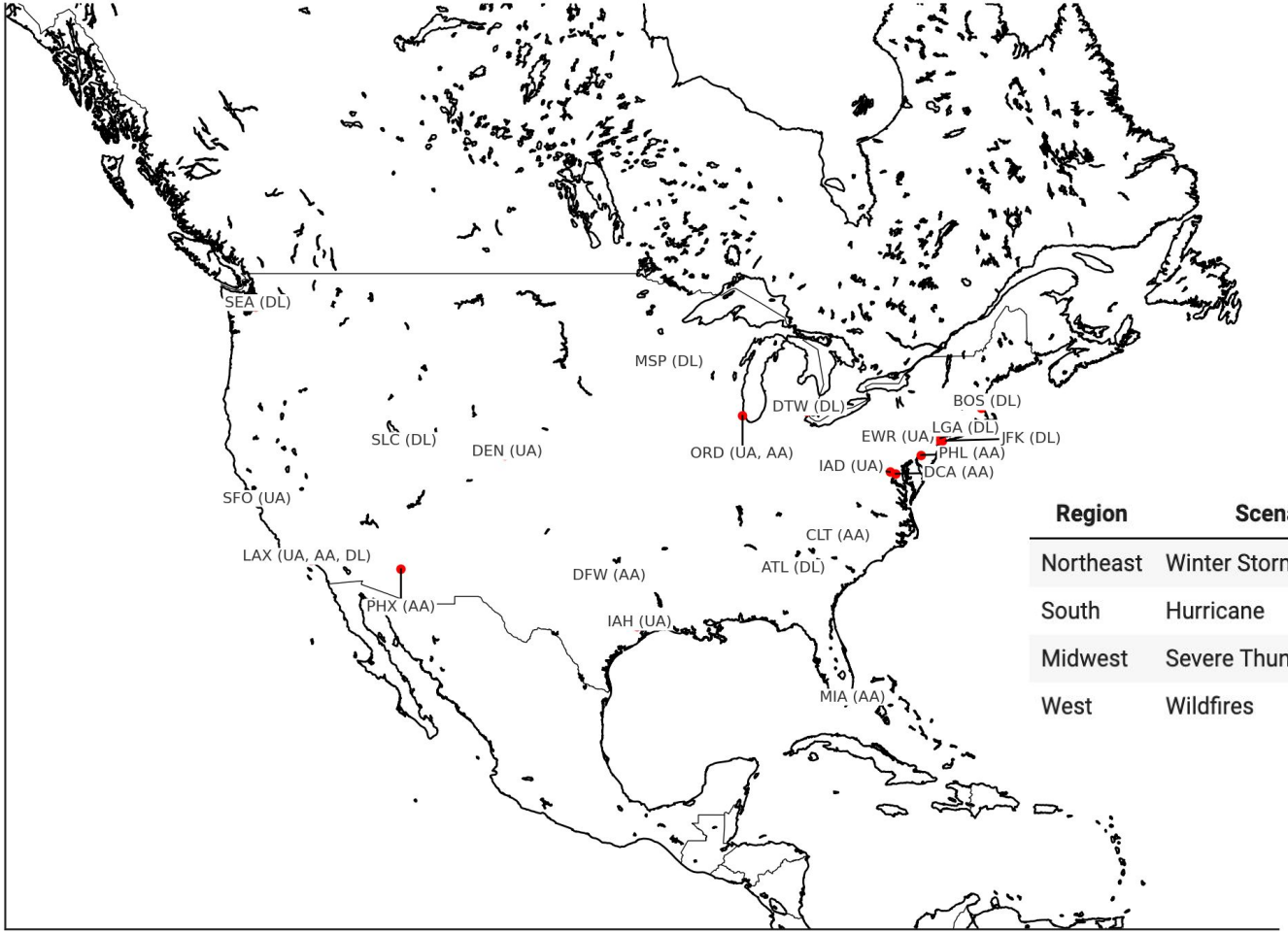
DH8
AA,24,CLT,3876,CHS,3806,,0,DH8
319 CR7
AA,24,CLT,3876,CLE,3486,,0,319

US Hub Airports for UA, DL, AA



Region	Scenario	Probability of Cancellation Given Event
Northeast	Winter Storm	0.50
South	Hurricane	0.65
Midwest	Severe Thunderstorms	0.40
West	Wildfires	0.30

1. Northeast: Winter Storm
EWR, IAD, PHL, DCA, BOS, JFK, LGA

2. South: Hurricane
IAH, CLT, DFW, MIA, ATL

3. Midwest: Severe Thunderstorm
ORD, MSP, DTW

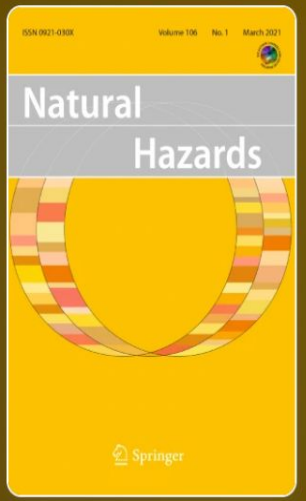
4. West Wildfires
SFO, DEN, LAX, SEA, PHX, SLC

Home › Natural Hazards › Article

The vulnerability of the European air traffic network to spatial hazards

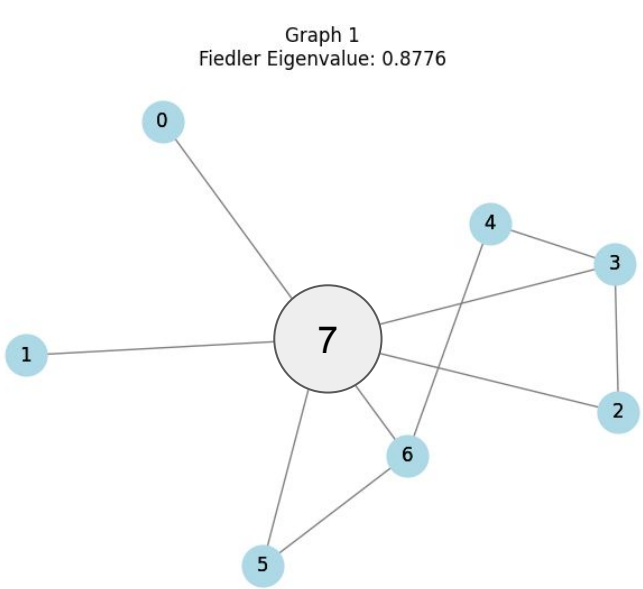
Original Paper | Open access | Published: 19 August 2011

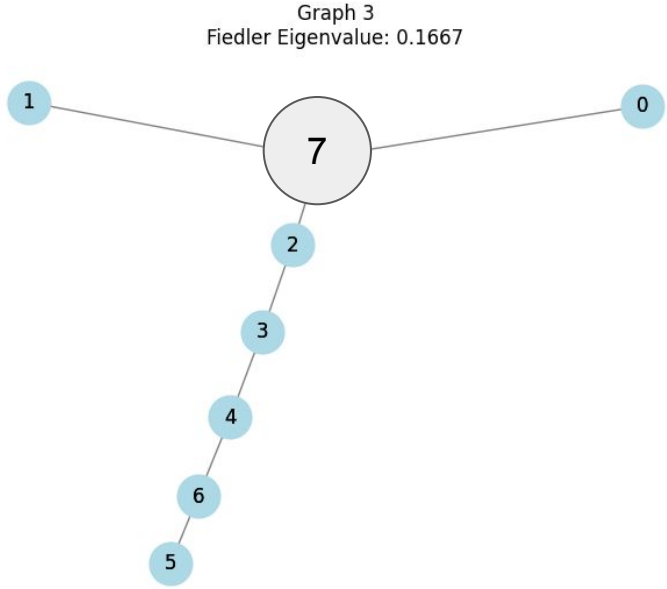
Volume 60, pages 1027–1036, (2012) Cite this article



Simplified Proximity Metrics: Geographic constraints are simplified

Hazard Specificity: It doesn't account for the varying nature and duration of different hazards.


Graph 1
Fiedler Eigenvalue: 0.8776
0
4
3
1
7
2
6
5


Graph 3
Fiedler Eigenvalue: 0.1667
1
0
7
2
3
4
6
5

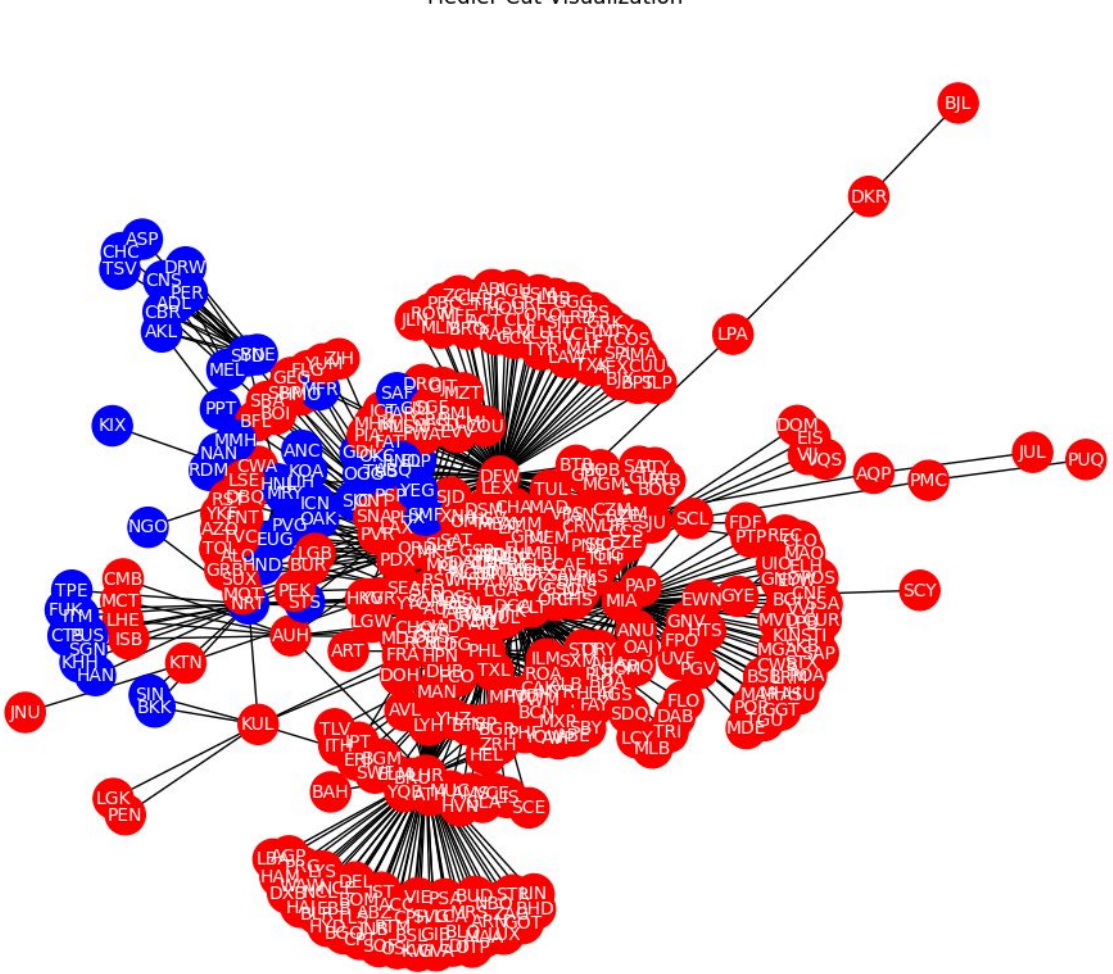
Calamity Simulation

Define distance of edge as d_{ij} **= Haversine distance of flight route from hub *i* to destination *j*.** Then,

$$\mathbb{P}(\text{edge } ij \text{ is removed}) = \frac{k_i}{d_{ij}}$$

For a given “scenario”, we cycle through each of the hubs, ***i***. For each hub, we remove a proportion ***p*** of routes with the above probability distribution. $k_i > 0$ is found so that

$$\sum_j \frac{k_i}{d_{ij}} = 1 \implies k_i = \frac{1}{\sum_j 1/d_{ij}}$$



Fiedler cut for AA:
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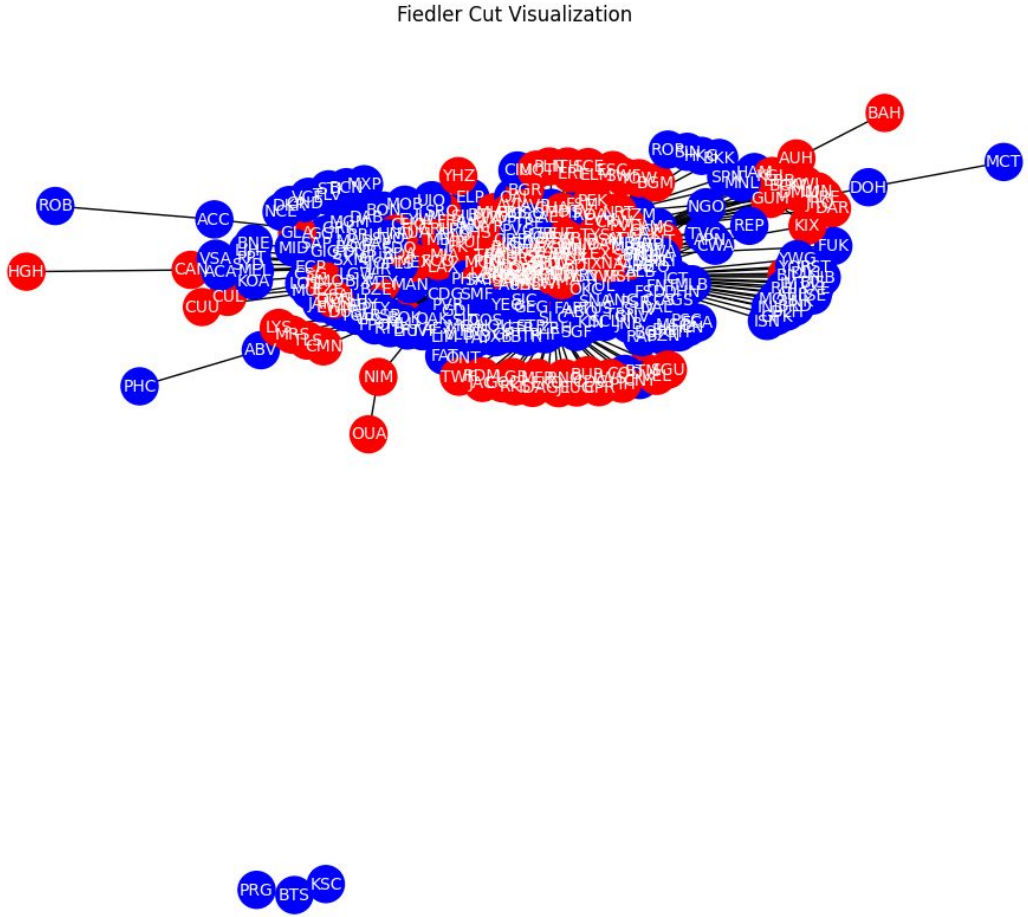
Partition 2: ['ABE', 'ABI', 'ABZ', 'ACC', 'ACT', 'AEX', 'AGP', 'AGS', 'AGU', 'ALB', 'ALO', 'AMA', 'AMM', 'AMS', 'ANU', 'AQP', 'ARN', 'ART', 'ASU', 'ATH', 'ATL', 'AUA', 'AUH', 'AUS', 'AVL', 'AVP', 'AZO', 'BAH', 'BCN', 'BDA', 'BDL', 'BFL', 'BGI', 'BGM', 'BGO', 'BGR', 'BHD', 'BHM', 'BJL', 'BJX', 'BLQ', 'BLR', 'BMI', 'BNA', 'BOG', 'BOI', 'BOM', 'BOS', 'BPT', 'BRO', 'BRU', 'BSB', 'BSL', 'BTR', 'BTV', 'BUD', 'BUF', 'BUR', 'BWI', 'BZE', 'CAE', 'CAK', 'CCS', 'CDG', 'CHA', 'CHO', 'CHS', 'CID', 'CLE', 'CLL', 'CLO', 'CLT', 'CMB', 'CMH', 'CMI', 'CNF', 'COS', 'COU', 'CPH', 'CPT', 'CRP', 'CUN', 'CUR', 'CUU', 'CVG', 'CWA', 'CWB', 'CZM', 'DAB', 'DAY', 'DBQ', 'DCA', 'DEL', 'DEN', 'DFW', 'DKR', 'DOH', 'DOM', 'DRO', 'DSM', 'DTW', 'DUB', 'DUS', 'DXB', 'EBB', 'EDI', 'EIS', 'ELH', 'ELM', 'ERI', 'EVV', 'EWN', 'EWR', 'EYW', 'EZE', 'FAR', 'FAY', 'FCO', 'FDF', 'FLG', 'FLL', 'FLO', 'FNT', 'FPO', 'FRA', 'FSD', 'FSM', 'FWA', 'GCK', 'GCM', 'GEG', 'GGG', 'GGT', 'GIB', 'GIG', 'GJT', 'GLA', 'GND', 'GNV', 'GOT', 'GPT', 'GRB', 'GRI', 'GRK', 'GRR', 'GRU', 'GSO', 'GSP', 'GUA', 'GVA', 'GYE', 'HAJ', 'HAM', 'HEL', 'HHH', 'HKG', 'HMO', 'HOU', 'HPN', 'HSV', 'HTS', 'HVN', 'HYD', 'IAD', 'IAH', 'ICT', 'ILM', 'IND', 'IPT', 'ISB', 'ISP', 'IST', 'ITH', 'JAN', 'JAX', 'JFK', 'JLN', 'JNB', 'JNU', 'JUL', 'KIN', 'KTN', 'KUL', 'KWI', 'LAS', 'LAW', 'LBA', 'LBB', 'LCA', 'LCH', 'LEX', 'LFT', 'LGA', 'LGB', 'LGK', 'LGW', 'LHE', 'LHR', 'LIM', 'LIN', 'LIR', 'LIS', 'LIT', 'LPA', 'LPB', 'LRD', 'LRM', 'LSE', 'LUX', 'LYH', 'LYS', 'MAA', 'MAD', 'MAF', 'MAN', 'MAO', 'MAR', 'MBJ', 'MCI', 'MCO', 'MCT', 'MDE', 'MDT', 'MEM', 'MEX', 'MFE', 'MGA', 'MGM', 'MHH', 'MHK', 'MHT', 'MIA', 'MKE', 'MLB', 'MLI', 'MLM', 'MLU', 'MOB', 'MQT', 'MRS', 'MSN', 'MSP', 'MSY', 'MTY', 'MUC', 'MVD', 'MXP', 'MYR', 'MZT', 'NAS', 'NBO', 'NCE', 'NCL', 'OAJ', 'OMA', 'ONT', 'ORD', 'ORF', 'ORY', 'OSL', 'OTP', 'PAP', 'PBC', 'PBI', 'PDX', 'PEK', 'PEN', 'PGV', 'PHF', 'PHL', 'PHX', 'PIA', 'PIT', 'PLS', 'PMC', 'PNS', 'POA', 'POP', 'POS', 'PRG', 'PSA', 'PSP', 'PTP', 'PTY', 'PUJ', 'PVD', 'PVR', 'QRO', 'RAP', 'RDU', 'REC', 'RIC', 'ROA', 'ROC', 'ROW', 'RST', 'RSW', 'RTB', 'RTM', 'SAL', 'SAN', 'SAP', 'SAT', 'SAV', 'SBA', 'SBP', 'SBY', 'SCE', 'SCL', 'SCY', 'SDF', 'SDQ', 'SEA', 'SFO', 'SGF', 'SHV', 'SJD', 'SJO', 'SJT', 'SJU', 'SKB', 'SLC', 'SLP', 'SNA', 'SOF', 'SPS', 'SRQ', 'SSA', 'STI', 'STL', 'STR', 'STT', 'STX', 'SUX', 'SVG', 'SWF', 'SXM', 'SYR', 'TGU', 'TLH', 'TLS', 'TLV', 'TOL', 'TPA', 'TRC', 'TRI', 'TUL', 'TVC', 'TXK', 'TXL', 'TYR', 'TYS', 'UIO', 'UVF', 'VCE', 'VIE', 'VIJ', 'VPS', 'VQS', 'VVI', 'WAW', 'XNA', 'YHZ', 'YKF', 'YOW', 'YQB', 'YUL', 'YUM', 'YVR', 'YYC', 'YYZ', 'ZAG', 'ZCL', 'ZIH', 'ZRH', 'CRW', 'PWM', 'SPI', 'LCY', 'PUQ']



Fiedler cut for DL:
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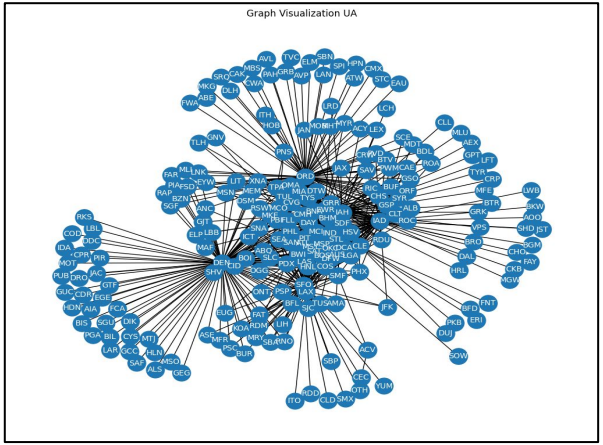
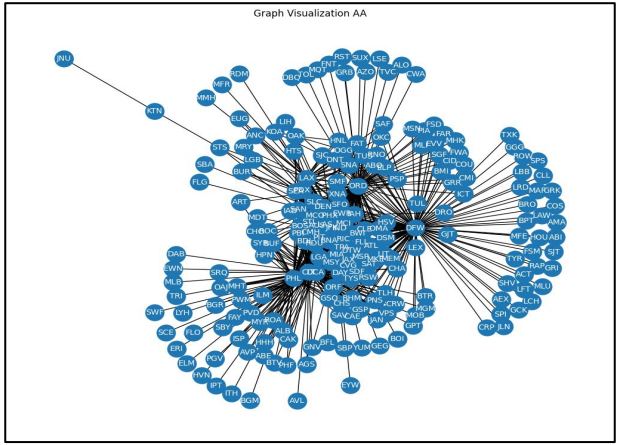
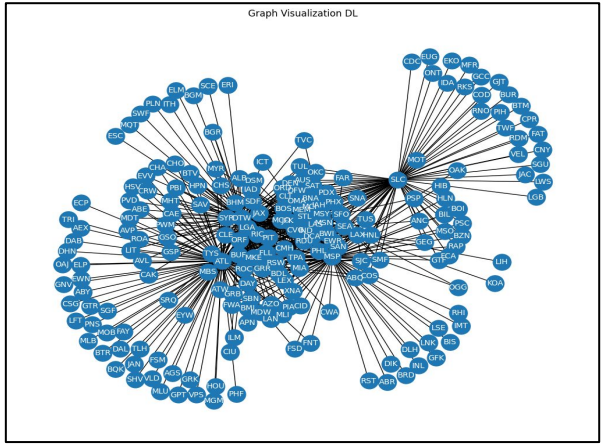
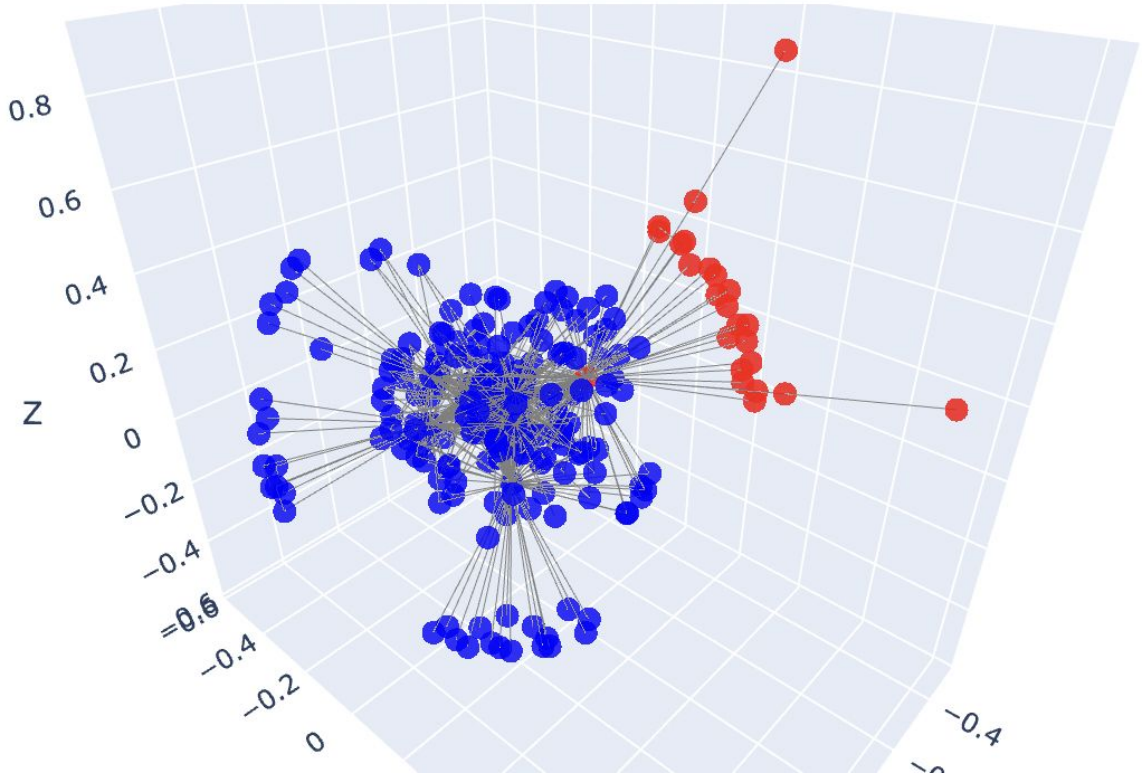
Partition 2: ['ABE', 'AUH', 'AUS', 'AVL', 'AVP', 'BAH', 'BDL', 'BGM', 'BGR', 'BIS', 'BJI', 'BMI', 'BNA', 'BOS', 'BQK', 'BTM', 'BTV', 'BUF', 'BUR', 'BZE', 'CAE', 'CAK', 'CAN', 'CDC', 'CHO', 'CID', 'CLT', 'CMN', 'CPR', 'CSG', 'CUL', 'CUN', 'DAR', 'DAY', 'DEN', 'DFW', 'DMM', 'DSM', 'DTW', 'EBB', 'EKO', 'ELM', 'ERI', 'ESC', 'EUG', 'EWR', 'EYW', 'FCO', 'GCC', 'GJT', 'GLA', 'GRR', 'GSO', 'GSP', 'GUM', 'HMO', 'HND', 'HNL', 'HPN', 'HRE', 'IAH', 'IDA', 'ILM', 'IMT', 'IND', 'ITH', 'JAC', 'JAX', 'JRO', 'KGL', 'KIX', 'KWI', 'LEX', 'LGA', 'LGB', 'LIT', 'LUN', 'LWS', 'MBJ', 'MCI', 'MCO', 'MDT', 'MEM', 'MEX', 'MFR', 'MHT', 'MIA', 'MKE', 'MQT', 'MRS', 'MSN', 'MSY', 'MTY', 'NIM', 'NRT', 'OGG', 'OMA', 'ORD', 'ORF', 'OUA', 'PBI', 'PEK', 'PHL', 'PIH', 'PIT', 'PLN', 'PUJ', 'PVD', 'RDM', 'RDU', 'RIC', 'RKS', 'RNO', 'RSW', 'SAN', 'SAT', 'SAV', 'SCE', 'SDF', 'SDQ', 'SGU', 'SLC', 'SRQ', 'STL', 'SWF', 'SYR', 'TPA', 'TWF', 'TYS', 'VEL', 'XNA', 'YHZ', 'YOW', 'YVR', 'PWM', 'HGH', 'LYS', 'TLS', 'CUU']



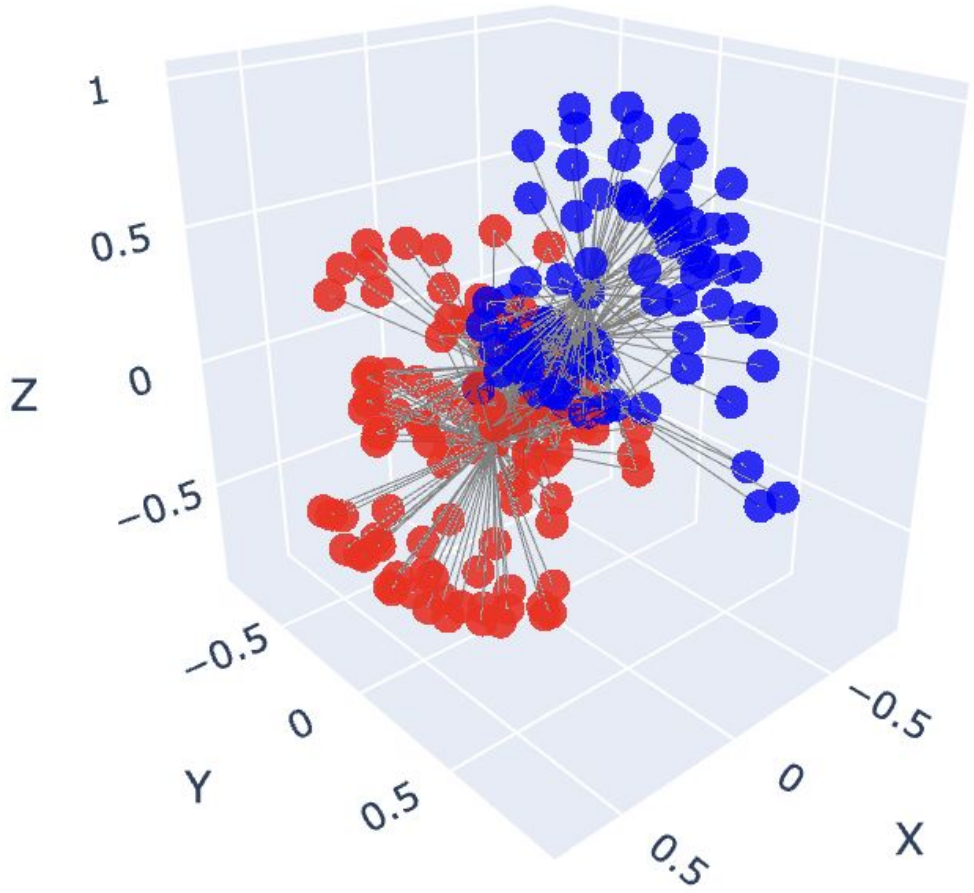




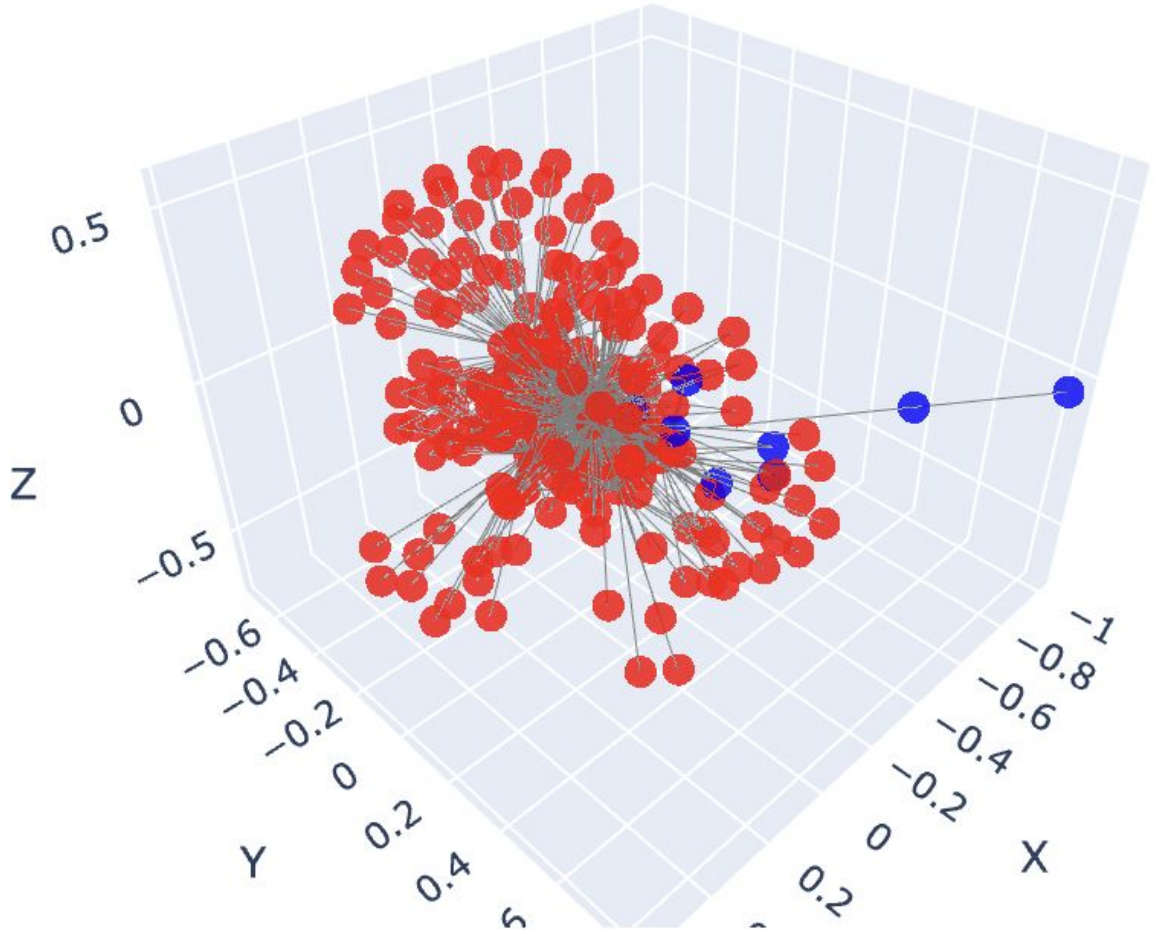
Connected Components Sizes	Largest Connected Component Size	Algebraic Connectivity (λ2)	Diameter	Spectral Radius	Average Clustering Coefficient	Graph
[225]	225	0.35	4	22.45	0.57	Graph_UA
[215]	215	0.33	3	23.06	0.58	Graph_DL
[216]	216	0.27	4	23.67	0.59	Graph_AA



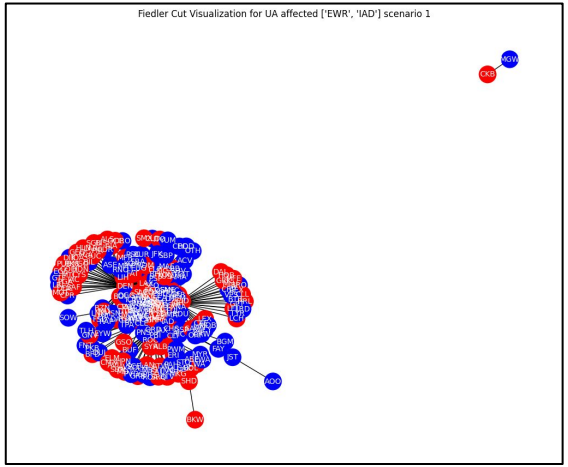
Airline	LCC	λ_2
United Airlines	213	0.282

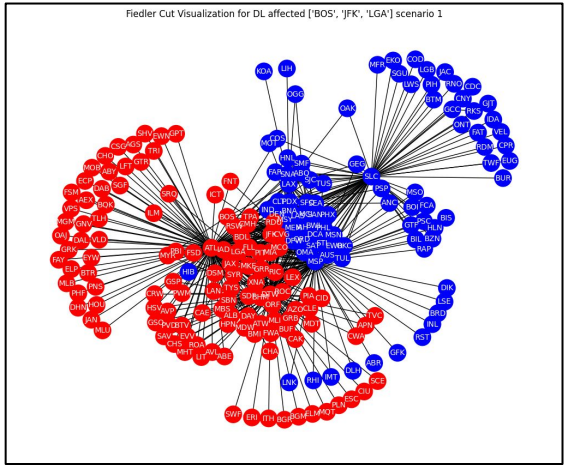


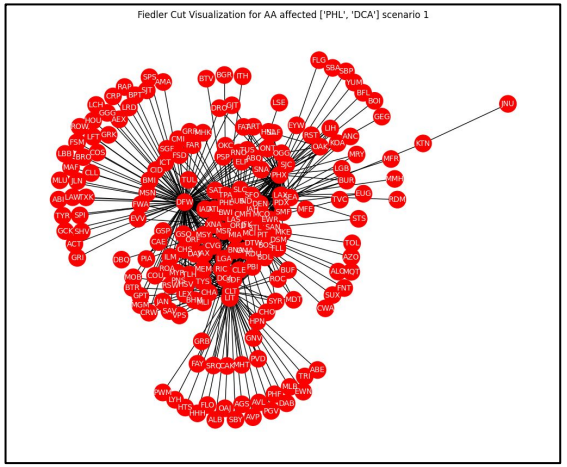
Airline	LCC	λ_2
Delta Airlines	201	0.361



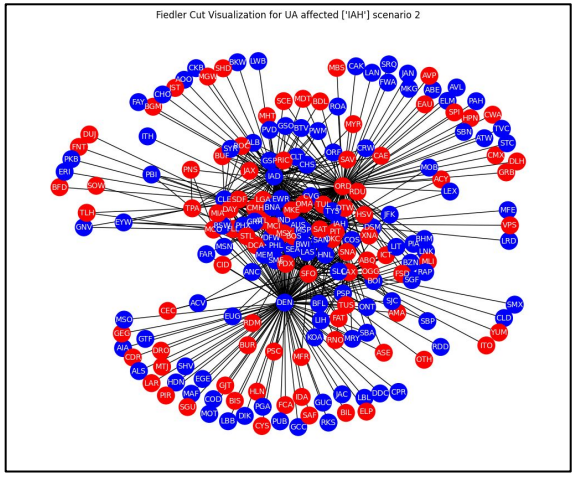
Airline	LCC	λ_2
American Airlines	205	0.274

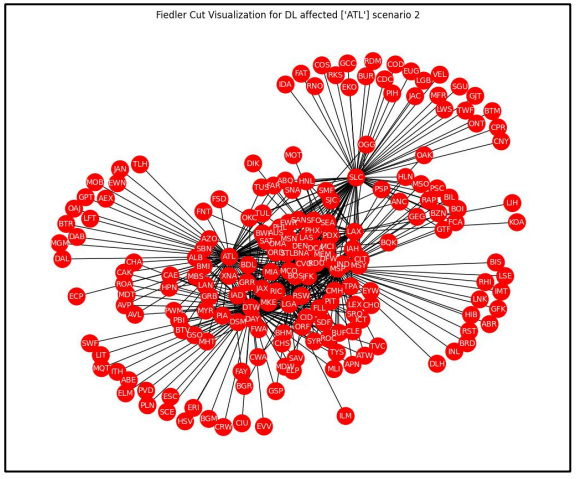


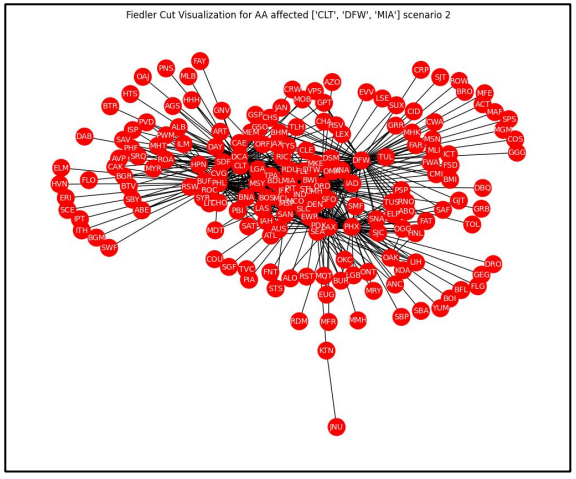




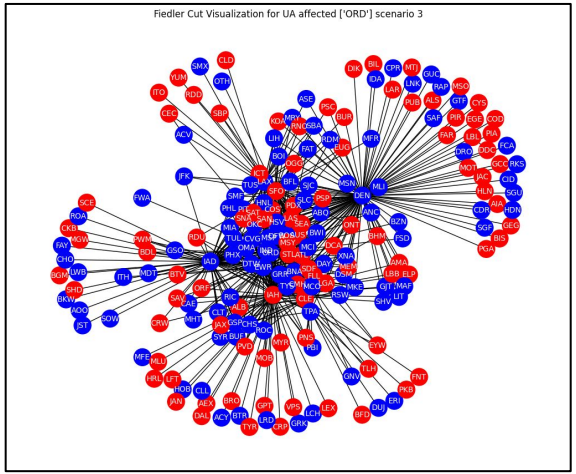
Connected Components Sizes	Largest Connected Component Size	Algebraic Connectivity (λ2)	Diameter	Spectral Radius	Average Clustering Coefficient	Graph (Northeast: Winter Storm)
[220, 1, 2, 1, 1]	220	0.00	5	20.31	0.46	UA Scenario 1
[215]	215	0.32	3	21.49	0.56	DL Scenario 1
[208, 1, 1, 1, 1, 1, 1, 1, 1]	208	0.00	4	21.69	0.47	AA Scenario 1

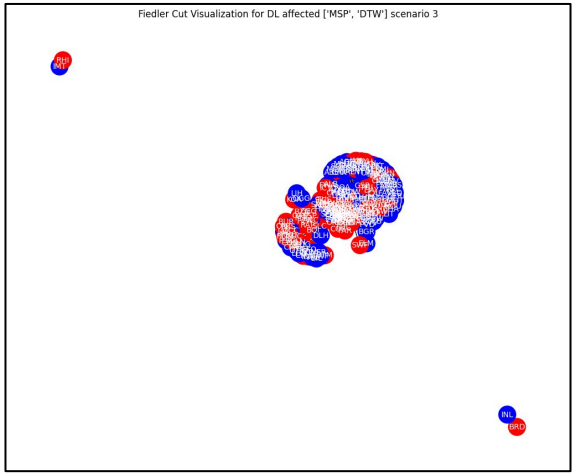


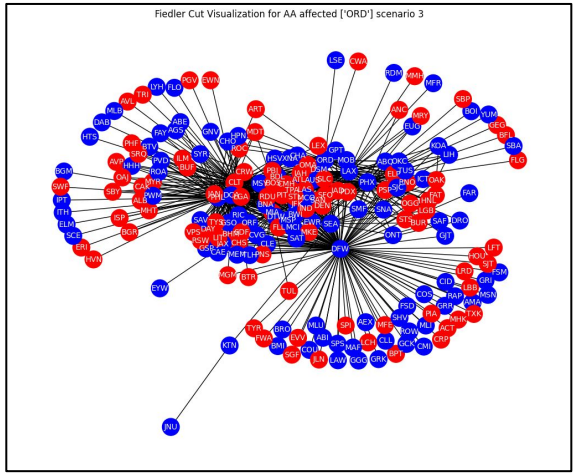




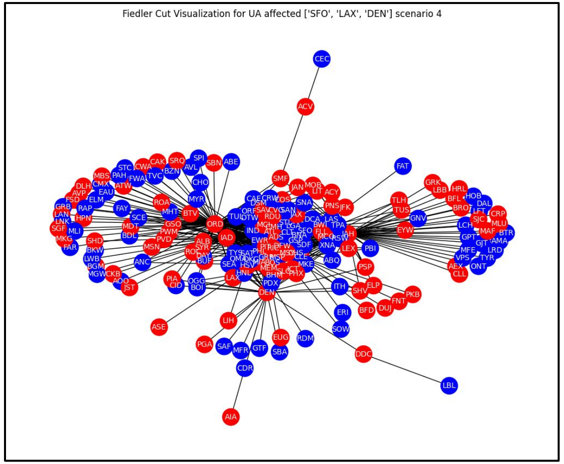
Connected Components Sizes	Largest Connected Component Size	Algebraic Connectivity (λ2)	Diameter	Spectral Radius	Average Clustering Coefficient	Graph (South: Hurricane)
[211, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	211	0.00	4	21.73	0.54	UA Scenario 2
[197, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	197	0.00	4	21.67	0.53	DL Scenario 2
[188, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	188	0.00	5	20.97	0.46	AA Scenario 2



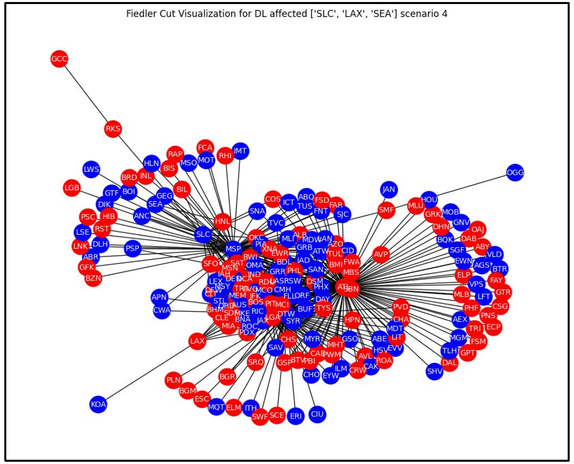




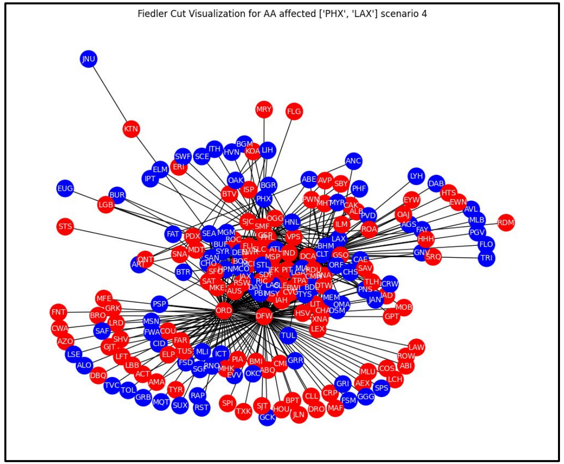
Connected Components Sizes	Largest Connected Component Size	Algebraic Connectivity (λ2)	Diameter	Spectral Radius	Average Clustering Coefficient	Graph(Midwest: Severe Thunderstorm)
[1, 204, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	204	0.00	4	20.49	0.45	UA Scenario 3
[191, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1]	191	0.00	4	19.17	0.38	DL Scenario 3
[206, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	206	0.00	5	22.23	0.50	AA Scenario 3



Fiedler Cut Visualization for UA affected ['SFO', 'LAX', 'DEN'] scenario 4



Fiedler Cut Visualization for DL affected ['SLC', 'LAX', 'SEA'] scenario 4



Fiedler Cut Visualization for AA affected ['PHX', 'LAX'] scenario 4

Connected Components Sizes	Largest Connected Component Size	Algebraic Connectivity (λ2)	Diameter	Spectral Radius	Average Clustering Coefficient	Graph (West Wildfires)
[188, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	188	0.00	7	19.10	0.36	UA Scenario 4
[193, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]	193	0.00	5	21.61	0.49	UA Scenario 4
[208, 1, 1, 1, 1, 1, 1, 1, 1]	208	0.00	5	22.02	0.52	UA Scenario 4

Results - Lowest Change in Spectral Values

1. **Northeast: Winter Storm -** Delta

2. **South: Hurricane -** United

3. **Midwest: Severe Thunderstorm -** American

4. **West Wildfires -** American/Delta

Possible Extensions

Apply to all Transport Architecture - Routes, etc

Include Dynamic Nature of Routes - Non-Hubs becoming Hubs, etc

Increase Passenger Flow Consideration

From today! (Mitch/Dav) Modelling the routes as a delay based on H-SIR

Appendix

Algebraic Connectivity (λ2)	Spectral Radius	Average Clustering Coefficient	Graph	Change in Algebraic Connectivity (λ2)	Change in Spectral Radius	Change in Average Clustering Coefficient
0.00	20.31	0.46	UA Scenario 1	-0.35	-2.14	-0.11
0.32	21.49	0.56	DL Scenario 1	**-0.01**	**-1.58**	**-0.02**
-0.00	21.69	0.47	AA Scenario 1	-0.27	-1.98	-0.12
-0.00	21.73	0.54	UA Scenario 2	-0.35	**-0.72**	**-0.03**
-0.00	21.67	0.53	DL Scenario 2	-0.33	-1.40	-0.05
-0.00	20.97	0.46	AA Scenario 2	**-0.27**	-2.71	-0.13

Appendix

Algebraic Connectivity (λ2)	Spectral Radius	Average Clustering Coefficient	Graph	Change in Algebraic Connectivity (λ2)	Change in Spectral Radius	Change in Average Clustering Coefficient
-0.00	20.49	0.45	UA Scenario 3	-0.35	-1.96	-0.11
-0.00	19.17	0.38	DL Scenario 3	-0.33	-3.89	-0.20
-0.00	22.23	0.50	AA Scenario 3	**-0.27**	**-1.45**	**-0.08**
-0.00	19.10	0.36	UA Scenario 4	-0.35	-3.35	-0.21
-0.00	21.61	0.49	DL Scenario 4	-0.33	**-1.46**	-0.09
-0.00	22.02	0.52	AA Scenario 4	**-0.27**	-1.66	**-0.07**

References

Wilkinson, S.M., Dunn, S. & Ma, S. The vulnerability of the European air traffic network to spatial hazards. *Nat Hazards* **60**, 1027–1036 (2012). https://doi.org/10.1007/s11069-011-9885-6

https://networks.skewed.de/net/openflights

OpenAI: ChatGPT

Notes of CompSci 521