Resource Optimization for Air Mobility Under Emergency Situations

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Research Questions

- Dynamic Airspace Configuration
- Pre-Disaster Outbound Flight Planning

Dynamic Airspace Configuration

- The current National Airspace System (NAS) is reaching capacity due to increased air traffic.
- It is based on outdated pre-tactical planning.
- We proposed a more dynamic airspace configuration (DAC) approach that could increase throughput and accommodate fluctuating traffic, especially for emergencies.

- We try to find an optimal plan to allocate non-busy airports' air traffic control resources to assist busy airports with possibly more delays.
- Our goal is to balance the workload of different airports during emergency evacuations or other busy scenarios.

How to balance the unbalanceness?

- We first calculated the average number of non-delayed and delayed flights handled by airports within each cluster, where m is the total number of flights in the cluster I
- We then calculated the variance of the Fi and Di over all clusters, noted as S. This value helps to quantify the workload unbalance within the whole airspace in scope.
- We want to minimize these variances.

$$F_i = \frac{\sum_{k=1}^{m} f_k}{m}$$

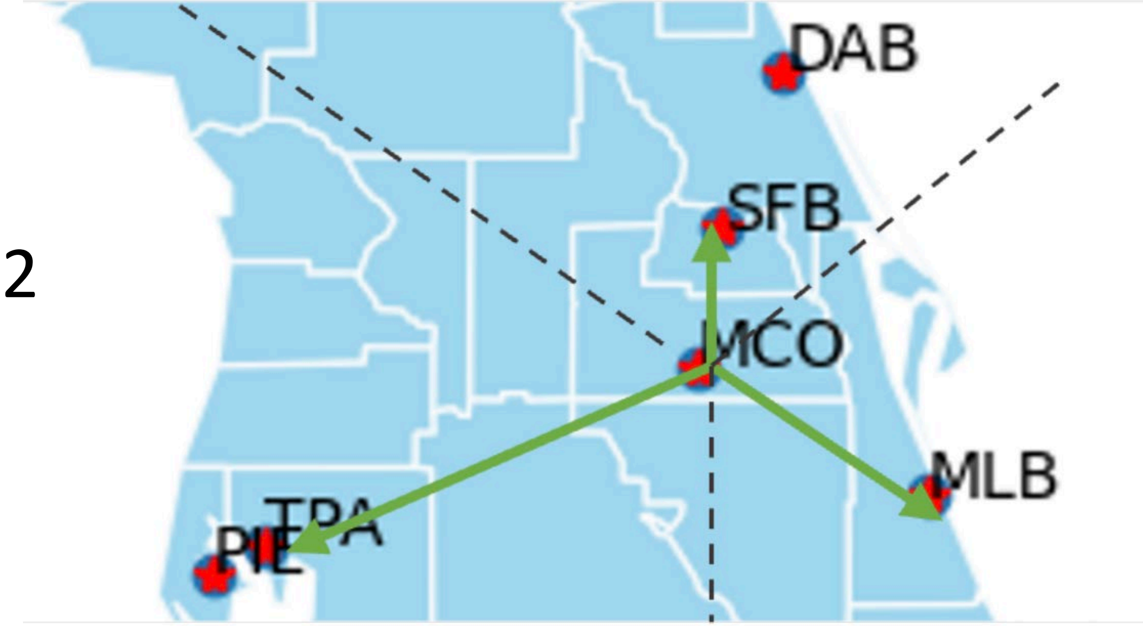
$$D_i = \frac{\sum_{k=1}^{m} d_k}{m}$$

$$S_D = \frac{\sum_{i=1}^{n} (D_i - D)^2}{n-1}$$

$$S_F = \frac{\sum_{i=1}^{n} (F_i - F)^2}{n-1}$$

Modeling of the Florida airspace

- Step 1: Generating Initial Airport Adjacency Graph (IAG)
- We identify if two nodes are connectible based on the geographic location.
- We define that if two airports, V 1 and V 2 are connected if V 2's is the closest neighbor geographical neighbor of V 1 at the same azimuth.
- This is a simplified implementation of Voronoi diagram



Assigning workloads

- Step 2: Creating Hybrid Airport Adjacency Graph (HAG)
- We assigned edge weights for each connection of airports.
- In HAG, airports in IAG that are less busy and geographically closer should have stronger connections to their neighbors, easy to request for collaboration…
- The busy airports should avoid being clustered together, have better not group with them at the moment…
- Collaborating airports should satisfy geographic distance constraints.

- A modified radial-based kernel is chosen to encode the workload into edge weight

$$load_{ij} = \frac{d_i + d_j}{f_i + f_j}$$

$$w_{i,j} = B^{((1-\lambda)(100load_{ij})+\lambda d_{ij}-shift)}$$

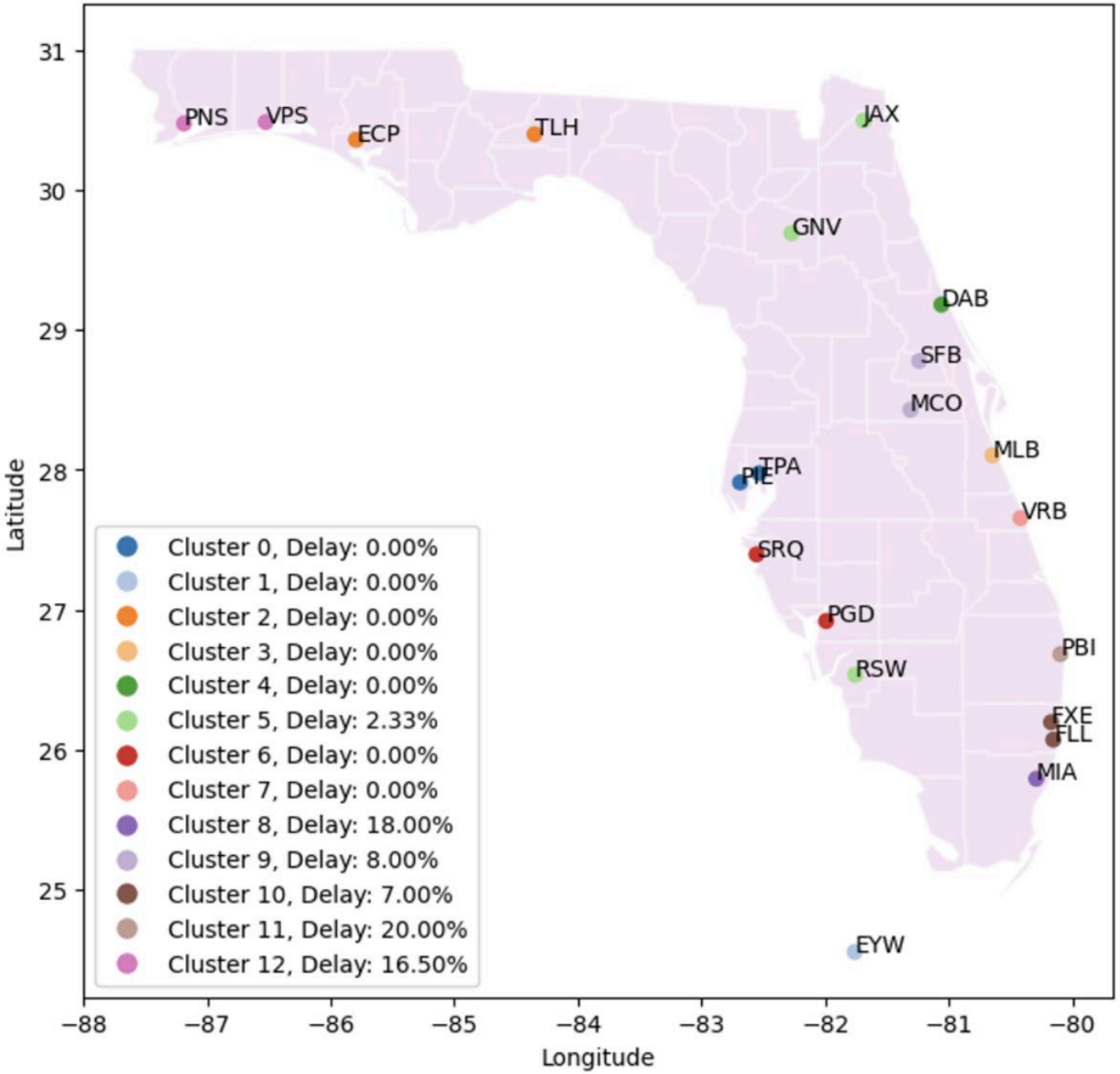
- i and j are two connected nodes, d is the number of delayed flights in this time window, f is the total number of flights in this time window.
- loadij is the percentage of delayed flights of node i and j and normalized between 0 and 1.
- dij is the geographical distance between the two airports.
- λ is the geographical weight factor in balancing between considering geographical distance and gross delay ratio.

Adaptive Spectral Clustering

- Mathematically, we project adjacency matrix of the Hybrid Airport Adjacent Graph to a lower dimension to remove redundancy and noise, then, clustering is done on the low-dimension.
  - **SVD Projection:** we calculate the degree matrix of the graph; The degree matrix is a diagonal matrix where the value at entry (i, i) is the degree of the node i. Then calculate the eigenvalues and eigenvectors of the degree matrix; then we sort them based on the eigenvalues.
  - **Autoencoder Projection:** we use the encoder to compress each airport in the graph (each row) into lower dimensions. This autoencoder contains two Dense layers for its encoder and decoder respectively.

- We perform the k-means clustering algorithm with an initial k value equal to half of the airports on the low dimension data to get the initial clustering result.
- Scan each cluster in the initial clustering result, if any cluster contains more than three airports or with a diameter greater than 100 nautical miles (the typical transmission range that aircraft can communicate directly).
  - We increase the number of clusters by 1 and simultaneously, increase the geographical weight λ by 0.1, but λ can not exceed 0.5.
  - Thus, the HAG is updated and we re-run the clustering algorithm until all constraints are meet

- After spectral clustering on HAG, the airports that are geographically close and with relatively low workloads are combined as a new cluster. Simultaneously, the busy airports with more delayed flights will be picked up and isolated.



Refining

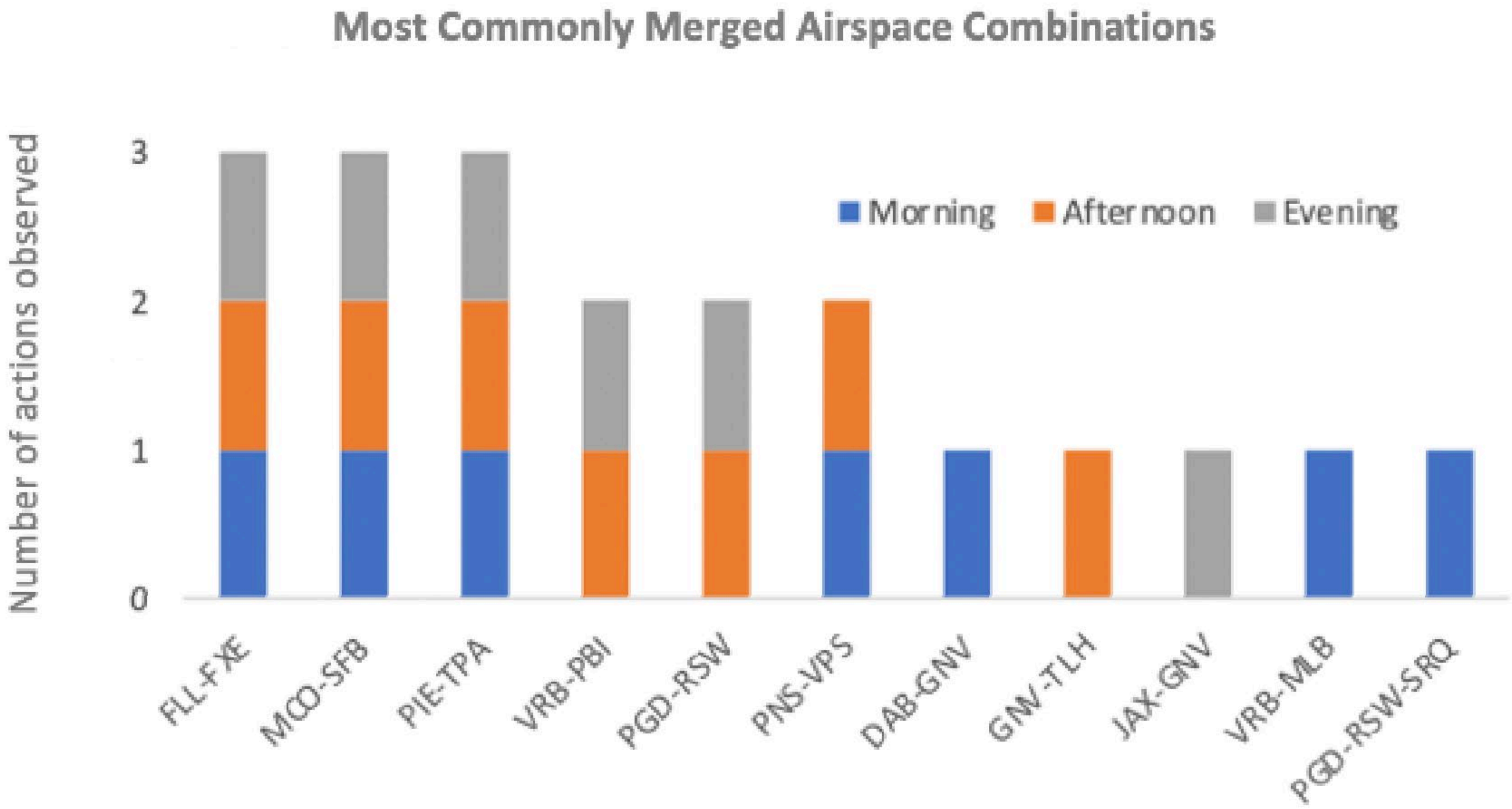
- Step 1: we created a ranked list of busy airports based on:
  - (a) a user-defined priority level with a default value of zero,
  - (b) the number of delayed flights,
  - (c) delay ratio,
  - (d) number of scheduled flights within the predicted time window.
- Step 2: we scanned all airports within 100 nautical miles of the busy airports in step one and determine if an airport can be merged to assist an adjacent busy airport based on these criteria:
  - (a) distance,
  - (b) number of predicted delayed flights,

Results

TABLE I
REDUCTION ON UNBALANCE LEVEL AFTER RECONFIGURATION AT DIFFERENT TIMES ON THE SAME DAY

	Handling regular flights	Handling delayed flights
7:00-9:00 (Low traffic)	42.85%	10.8%
12:00-14:00 (High traffic)	56.9%	61.04%
19:00-21:00 (Medium traffic)	42.86%	60.1%

Our solution can significantly balance the workload of ATC during busy hours


Most Commonly Merged Airspace Combinations
Number of actions observed
0
1
2
3
Morning
Afternoon
Evening
FLL-FXE
MCO-SFB
PIE-TPA
VRB-PBI
PGD-RSW
PNS-VPS
DAB-GNV
GNV-TLH
JAX-GNV
VRB-MLB
PGD-RSW-SRQ

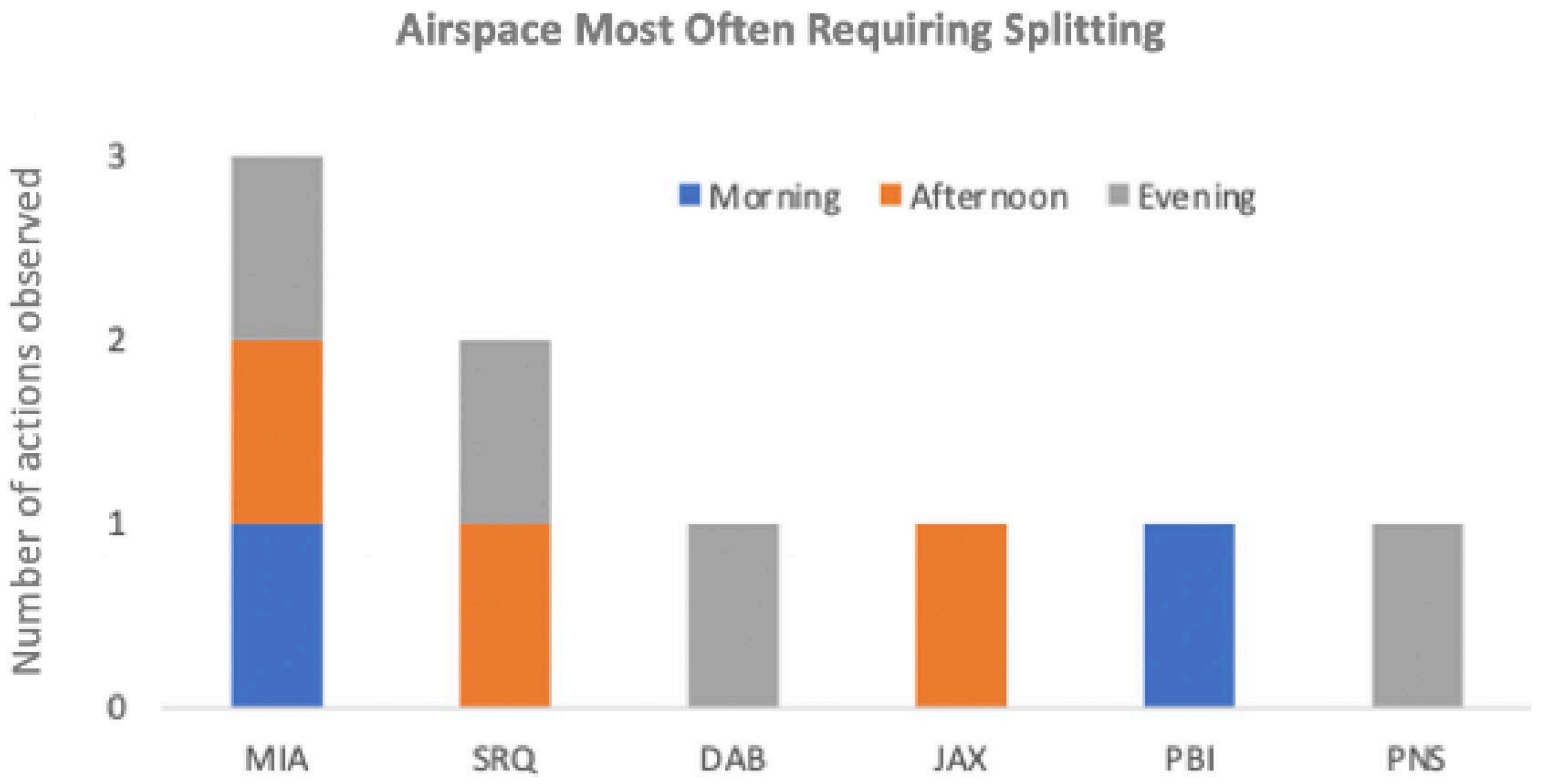

Airspace Most Often Requiring Splitting
Number of actions observed
0
1
2
3
Morning
Afternoon
Evening
MIA
SRQ
DAB
JAX
PBI
PNS

TABLE III

COMPARISON OF TIME REQUIRED IN REAL-TIME APPLICATION BETWEEN SVD AND AUTOENCODER

HAG's dimension	SVD prediction (10^{-5} second)	Autoencoder prediction (10^{-5} second)	Autoencoder Training time (second)
7*7	43.9	1.16	27.78
10*10	44.8	1.70	27.04
15*15	44.5	4.06	69.47
18*18	48.1	3.30	64.67
21*21	373.8	3.54	65.98

Paper:

- Feng, Ke, Dahai Liu, Yongxin Liu, Hong Liu, and Houbing Song. "GraphDAC: A Graph-Analytic Approach to Dynamic Airspace Configuration." In *2023 IEEE 24th International Conference on Information Reuse and Integration for Data Science (IRI)*, pp. 235-241. IEEE, 2023.

Code:

https://github.com/KeFenge2022/GraphDAC

Thank You

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