A Comparison of Algorithm Generated Sectorizations

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June 29, 2009
8th ATM R&D Seminar
Napa, California
Background

• Today’s sectors are static and designed around demand flows.
• Future air transportation system could better accommodate changes in demand with more flexible airspace.
• Airspace partitioning algorithms are necessary for flexible airspace design to expedite the design cycle.
• Several airspace partitioning algorithms have been developed to resectorize the airspace in response to changing demand.
Objectives

• Algorithm Objectives: Create sectorizations that
  – Increase system capacity and efficiency
  – Balance controller workload
  – Minimize required airspace resources

• Experiment Objective: Compare algorithm generated sectorizations
  – National scale - 20 continental US centers
  – Current (1x) and future (1.5x) traffic levels
Outline

• Airspace partitioning algorithms
• Experiment design
• Visual sectorization comparison
• Metrics comparison results
• Summary comparison
Airspace Partitioning Algorithms

- Flight Clustering
- Voronoi Genetic
- Mixed Integer Programming
Flight Clustering

• Use clustering criteria to group flights to improve Dynamic Density.

• Clustering criteria:
  – Current and projected position
  – Heading and speed variance
  – Ascending and descending aircraft
  – Distance from major axis of the group
  – Heading with respect to major axis of group

Voronoi Genetic

Voronoi Diagram airspace representation

Genetic Algorithm airspace optimization

Optimization Function: Maximize (capacity - peak aircraft count)

Mixed Integer Programming

• Tile the airspace with hex cells.
• Determine connectivity between cells.
• Cluster cells to maximize connectivity while trying to balance number of flights in each sector.

Experiment Design

- Flight Schedules
  - Unconstrained Simulation
    - Unconstrained flight tracks
  - Generate Sectorization
    - Sector boundaries
  - Estimate Sector Capacities
    - Sector capacities
  - Sector Capacity Constrained Simulation
    - Constrained flight tracks and delays
  - Comparison Metrics
Experiment Design

Flight Schedules

- Unconstrained Simulation
- Generate Sectorization
- Estimate Sector Capacities
- Sector Capacity Constrained Simulation
- Comparison Metrics

Flight Schedules
- 4/21/2005
- High volume
- Low weather delays
Experiment Design

Flight Schedules → Unconstrained Simulation

• All flights fly without delays
• Generate unconstrained flight tracks

Generate Sectorization

unconstrained flight tracks → sector boundaries

Estimate Sector Capacities

sector capacities → Sector Capacity Constrained Simulation

constrained flight tracks and delays → Comparison Metrics

Unconstrained Simulation

• All flights fly without delays
• Generate unconstrained flight tracks
Experiment Design

Generate Sectorization
- Conform to center boundaries
- 2 altitude layers
  - High: ~24,000 ft - ~35,000 ft
  - Super High: ~35,000 ft - above

Flight Schedules
→ Unconstrained Simulation
  → Generate Sectorization
    → sector boundaries
    → Estimate Sector Capacities
      → sector capacities
      → Sector Capacity Constrained Simulation
        → constrained flight tracks and delays
          → Comparison Metrics
Experiment Design

Estimate Sector Capacities
• $f(\text{flight tracks, sector boundary})$
• FAA formula: 5/3 average flight time through sector

Flight Schedules → Unconstrained Simulation → Generate Sectorization → Estimate Sector Capacities → Sector Capacity Constrained Simulation → Comparison Metrics

Unconstrained flight tracks → sector boundaries → sector capacities → constrained flight tracks and delays
**Experiment Design**

**Sector Capacity Constrained Simulation**
- Flights are delayed along flight plan route to meet sector capacity constraints
- Run both 1x and 1.5x demand

**Average total delay = 0.58 minutes**
Visual Comparison

High Altitude (~24,000 ft - ~35,000 ft) Fort Worth Center

Current Day Airspace (2005)

Flight Clustering

Voronoi Genetic

Mixed Integer Programming

- Large number of sectors
- Sectors oriented toward the center aligning with flows
- Less convex sector shape
Comparison Metrics

• Airspace Resource Metrics
  – Number of sectors
  – Complexity

• System Efficiency Metrics
  – Reduced delay
  – Recovered throughput

• Sector Balancing Metrics
  – Complexity balancing
  – Demand/Capacity balancing
Airspace Resource Results

Number of Sectors

- Mixed Integer Programming
- Voronoi Genetic
- Flight Clustering
- Current Day (2005)

Lower is Better
Airspace Resource Results

**Complexity** = Simplified Dynamic Density

= weight sum of 7 Dynamic Density components

Current Day (2005)

- Flight Clustering
- Voronoi Genetic
- Mixed Integer Programming

Lower is Better

1X

1.5X
System Efficiency Results

1.5X results

Flight Clustering
Voronoi Genetic
Mixed Integer Programming

Recovered Throughput

0% 20% 40% 60% 80% 100%

High Super-high

Average flight count for mid 8 hours
demand unconstrained

Recovered Throughput = 1 - \frac{m_d - m_t}{m_d - m_{t0}}

Reduced Delay

0% 20% 40% 60% 80% 100%

High Super-high

Reduced Delay = 1 - \frac{\varepsilon}{\varepsilon_0}
delay

current day sectorization
Results By Center

Recovered Throughput 1.5X

Reduced Delay 1.5X
Sector Balancing Results

1.5X results
Current Day (2005)
Flight Clustering
Voronoi Genetic
Mixed Integer Programming

Demand Complexity Standard Deviation

- High
- Super-high

Lower is Better

Demand/Capacity Ratio Standard Deviation

- High
- Super-high

Complexity balanced across sectors
Capacity placed where most demanded
### Summary and Conclusions

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<th>Recovered Throughput</th>
<th>Reduced Delay</th>
<th>Complexity Balancing</th>
<th>Demand/Capacity Balancing</th>
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*Voronoi Genetic does the best job of increasing system efficiency with minimal increase in number of sectors compared to current day.*
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