Optimizing Airspace Sectors for Time-Varying Demand Patterns Using Multi-Controller Staffing

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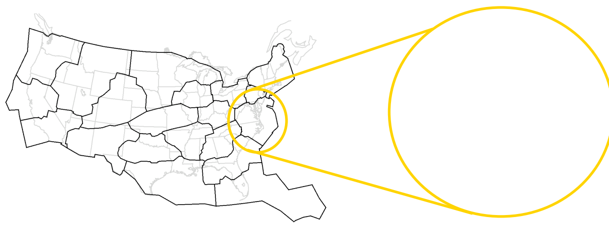
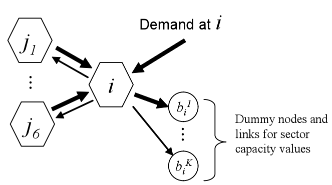
Preliminaries and Motivations

- Each enroute airspace sector is managed by a team of human controllers, providing navigational services and separating aircraft.
- As controller labor costs have increased from $83/flight in FY1998 to $138/flight in FY2006, it is crucial for the FAA to efficiently use controller resources.
- The concept of designing sector boundaries while considering controller staffing has been first introduced in this work, although it is one of the common means in practice to deal with demand variation over time and space.



Objective and Methodology

- Objective: to optimize sector boundaries over multiple periods while addressing demand variability by varying sector controller staffings at each period.
- The target airspace is decomposed into contiguous hex-cells. A mixed integer program groups hex-cells into sectors that align with traffic flows and minimize total controller hours.



Model Formulation

- Flow Conservation Constraints

$$\sum_{j\in A_i} x^t_{ji} + d^t_i = \sum_{j\in A_i} x^t_{ij} \quad ,\forall i\notin S, t\in T$$

$$\sum_{j\in A_i} x^t_{ji} + d^t_i = \sum_{j\in A_i\cup B_i} x^t_{ij} \quad ,\forall i\in S, t\in T$$

- Link Usage Constraints

$$x^t_{ij} \le M_{ij} q_{ij} \quad ,\forall i\in I, j\in A_i, t\in T$$

- Step-wise Sector Capacity Constraints (on Dummy Links)

$$M_{i,b_i^{k-1}} p^t_{i,b_i^k} \le x^t_{i,b_i^k} \le M_{i,b_i^k} p^t_{i,b_i^k} \quad ,\forall i\in S, k\in K, t\in T$$

- Outbound Flow Constraints

$$\sum_{j\in A_i} q_{ij} \le 1 \quad ,\forall i\notin S \qquad \sum_{j\in A_i} q_{ij} + \sum_{j\in B_i} p^t_{ij} \le 1 \quad ,\forall i\in S, t\in T$$

- Objective Function

$$\text{Min} \sum_{i\in S, j\in B_i, t\in T} f^t_{ij} p^t_{ij} + \mu \sum_{i\in I, j\in A_i, t\in T} c^t_{ij} x^t_{ij}$$

Decision Variables

x^t_{ij} : continuous variable of link flow at each time period.
q_{ij} : binary variable on whether link is chosen.
p^t_{ij} : binary variable on which sector capacity value is chosen at each time period.

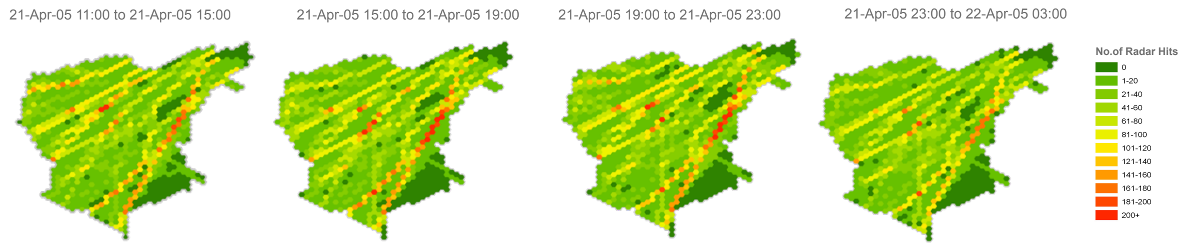
Demand Metric

d^t_i : demand at each hex-cells, measured as TZ radar hits

Cost Coefficients

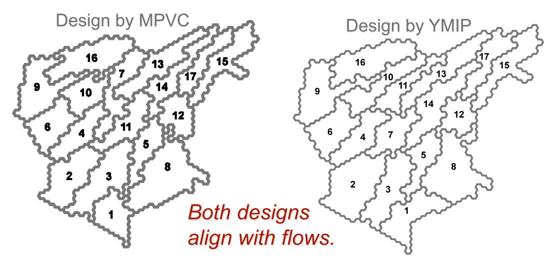
f^t_{ij} : fixed cost on dummy links, capitalizing controller usages
c^t_{ij} : variable link cost, defined as the inverse of aircraft crossings between two hex-cells

Demand Variation at Washington Air Route Traffic Control Center (ZDC)



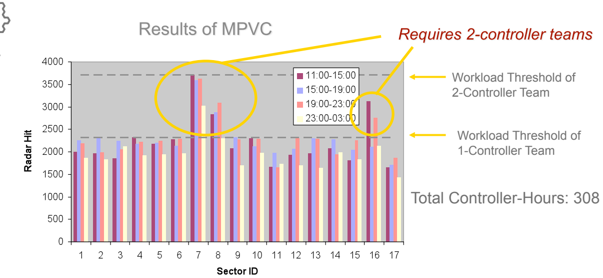
Experimental Results and Comparison with An Existing Model

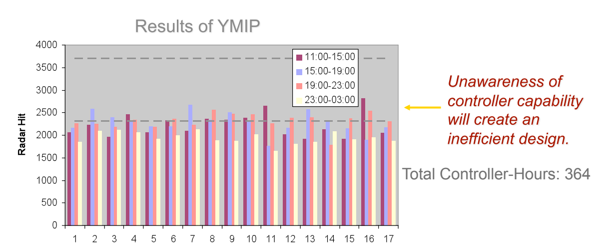
- ZDC airspace is tiled with 1043 hex-cells of equal size, 41 of which are selected as seeds and evenly distributed within the design area.
- Historical traffic data on April 21, 2005 are used to generate demand profiles for the 16-hour busy period of the day into four 4-hour intervals.
- We assume that at most two controller positions could be used at each resulting sector.
- Our model (MPVC) and workload balancing model (YMIP) are comparable in flow alignment but differ significantly in controller resource usage.



Model (MIP)	MPVC	YMIP
Planning Horizon	16 Hrs	
Duration per Period	4 Hrs	
Design Objective	Minimize no. of controller shifts and sectors; Minimize flow alignment cost	Balance workload among sectors; Minimize flow alignment cost
Required Controller-hours	**308**	**364**
Avg. Flight Dwell Time	8.0	8.5
BalDev+	59.1%	5.0%
BalDev-	-23.7%	-5.0%

Our model significantly reduces controller-hours!





Contribution and Future Works

- Given the time-varying nature of traffic, the sectorizations from this model not only accommodate the multi-period demand but also consider the overall efficiency of controller staffing requirements.
- Further investigation is required to specify how the capacity values link to controller staffing.
- Other non-controller resources that impact sector capacity could also be included to reflect those resource constraints.