Evaluation of Collaborative Rationing of En Route Resources

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DRAPER LABORATORY

Outline

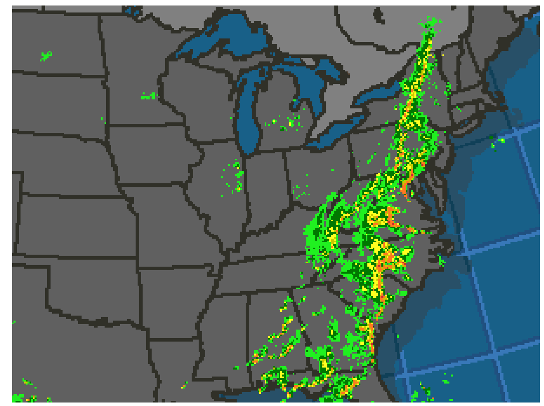
- The need for collaborative en route rationing
- Proposed routing schemes
- Evaluation methodology
  - Model for forecast/planning/execution
  - Metrics for comparison
- Scenarios
  - Mapping *weather* forecast to *capacity* forecast
  - Scenario selection
- Preliminary results
- Pending and future work

Background: Collaborative En-Route Rationing

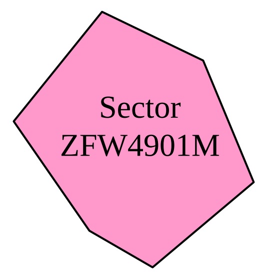
- Collaborative
  - Operational decisions concerning the Air Transportation System are made by many stakeholders
    - Numerous Airlines
    - Air Traffic Management and Air Traffic Control
    - General Aviation
    - Airport Authorities
- Rationing
  - At times demand exceeds capacity
  - Rationing ensures safe operation
- En-Route
  - Has had relatively little attention
  - Large potential improvement

Background: Definitions

- *Capacity*: The rate at which aircraft can be processed through airspace (given very high demand)
  - Numerous operational constraints determine capacity
  - Under normal conditions, controller workload and frequency congestion limit capacity
  - Occasionally, bad weather shuts down parts of airspace
- Resource: A high level En Route sector *s* at time *t* with capacity *c*



Sector Capacity at Time t: 2 Flights



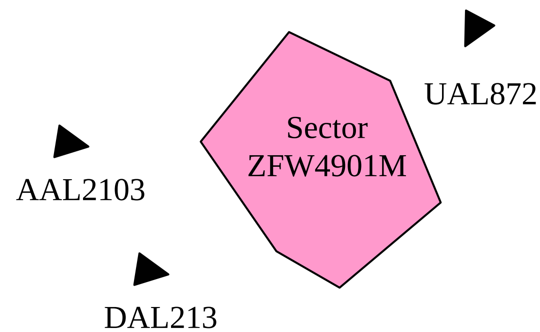
Proposed routing schemes

- First-Filed, First-Served
- Equalize Accrued Delay
- Randomized Rerouting
- Global Optimization

First-Filed, First-Served

- Priority for en route resources assigned when the flight plan is first filed
- Advantage:
  - Encourages (earlier) proactive planning of airspace usage.
- Disadvantages:
  - Unexpected spillover from other Flight Control Areas.
  - Lack of built-in *alternative* plans.
  - Potential for “gaming”.

Sector Capacity at Time t: 2 Flights



File Times

DAL213	1700
AAL2103	1720
UAL872	1732

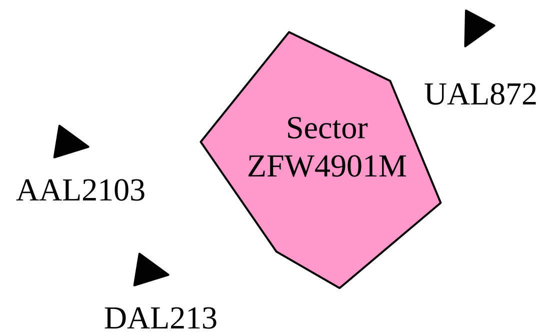
Resulting Flight Plans

DAL213	…ZFW4901M…
AAL2103	…ZFW4901M…
UAL872	~~…ZFW4901M…~~

Equalize Accrued Delay

- Allocate resources to uniformly distribute delay
  - Analogous to RBS-based slot assignment in GDP-E.
- Advantage:
  - No user is unduly delayed.
- Disadvantage:
  - Disregards nature of delay. Can be mechanical, crew-related, etc.

Sector Capacity at Time t: 2 Flights



<u>Delay Incurred by time T</u>

DAL213	30 min
AAL2103	21 min
UAL872	15 min

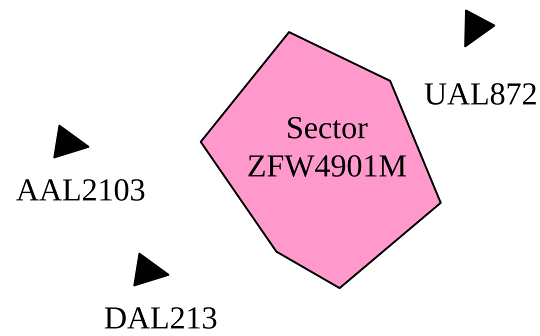
<u>Resulting Flight Plans</u>

DAL213	…ZFW4901M…
AAL2103	…ZFW4901M…
UAL872	~~…ZFW4901M…~~

Randomized Rerouting

- For each over-scheduled resource, re-route (randomly) selected subset of flights.
- Advantage:
  - “Pure” equitable allocation.
- Disadvantage:
  - *Maximum* capacities are respected, but sector loads remain unbalanced (favors most popular routes).
  - No *global* optimality guarantees.

Sector Capacity at Time t: 2 Flights



<u>Resulting Flight Plans</u>

DAL213	~~…ZFW4901M…~~
AAL2103	…ZFW4901M…
UAL872	…ZFW4901M…

Global (ATC-side) Optimization

- Resources allocated by a central (FAA) authority via extended Bertsimas/Stock MIP formulation.

- Advantage:
  - Global optimality guarantee.

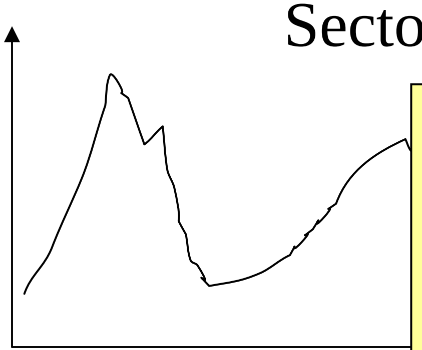
- Disadvantage:
  - Imperfect knowledge of stakeholder objectives and NAS state degrades user optimality.

Evaluation Method: Central Questions

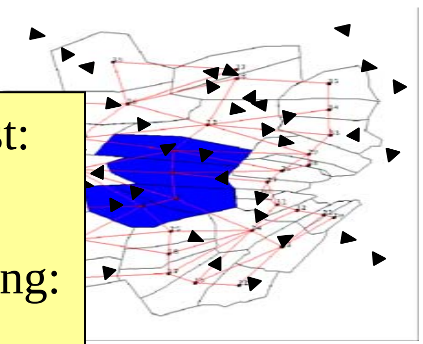
- Identify performance trade-off between planning horizon and forecast accuracy
  - Short horizon rerouting benefits from more reliable forecasting
  - Long horizon rerouting benefits from a greater number of system degrees of freedom
- Examine dynamic stability/flexibility of plans
  - How much of the current situation and previous planning should be deemed "frozen?"
- Quantify the benefit of increased user collaboration
  - Multiple Flight Plan Submission
  - Voluntary Rerouting

Evaluation Methodology: Planning/Information Model

Demand Forecast: Sector *x*



Current System State

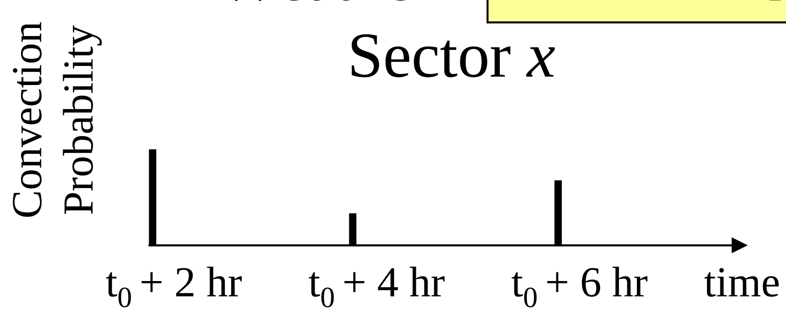


Source of Simulated Demand Forecast:
ETMS Data

Source of Simulated Weather Forecasting:
RTVS verified CCFP Data

Source of “Current” System State:
NEXRAD Data

Weather Forecast: Sector *x*



2. Plan

1. Forecast

3. Execute

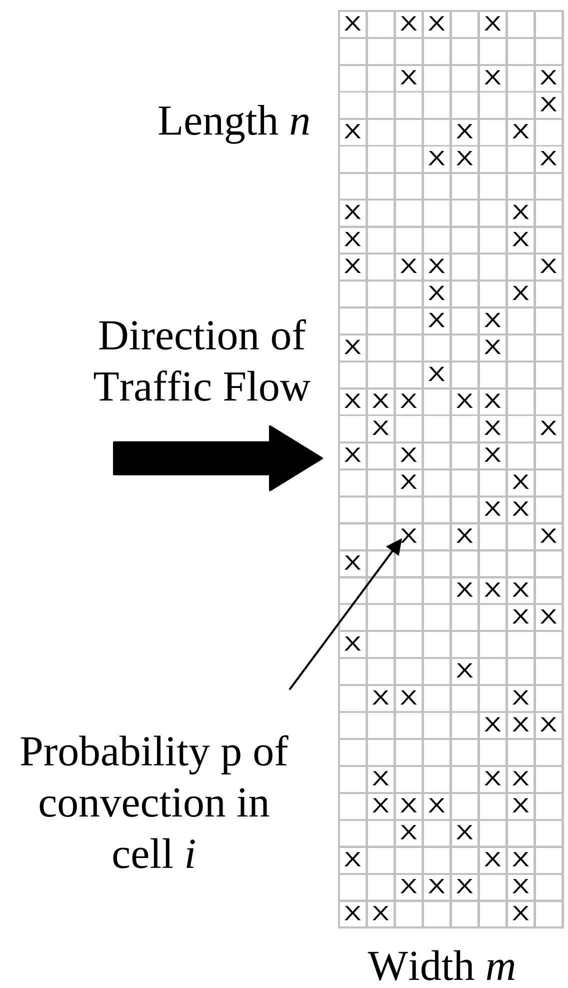
Receding Horizon
Control Problem

Evaluation Methodology: Metrics

- Total Benefit (Cumulative Delay Reduction)
- Delay Distribution
  - Overall
  - User-Specific (e.g. distribution for each airline)
- Sector Density
  - Safety Metric
  - Compare resulting number of "hot spots" with what actually occurred and Monitor Alert
- Per flight costs
  - Account for missed connections using DB1 database of connecting flight information

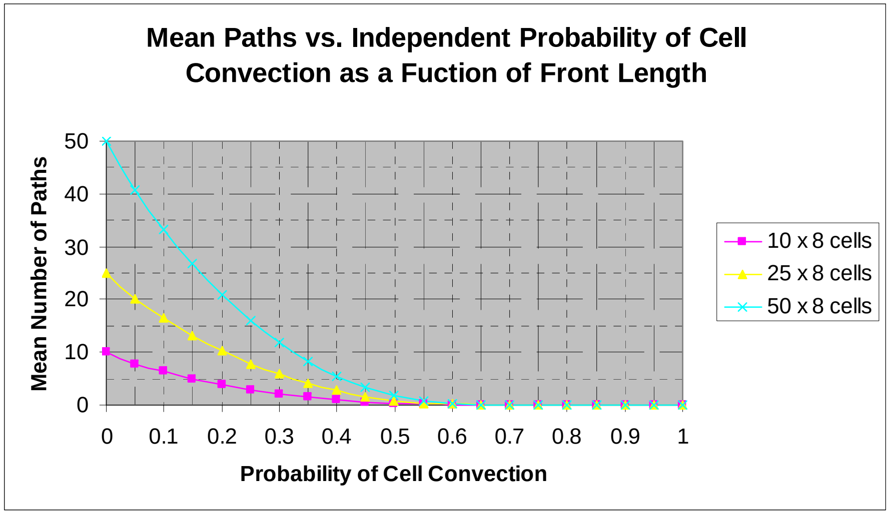
Scenarios:
Wx Forecast ⇒ *Capacity* Forecast

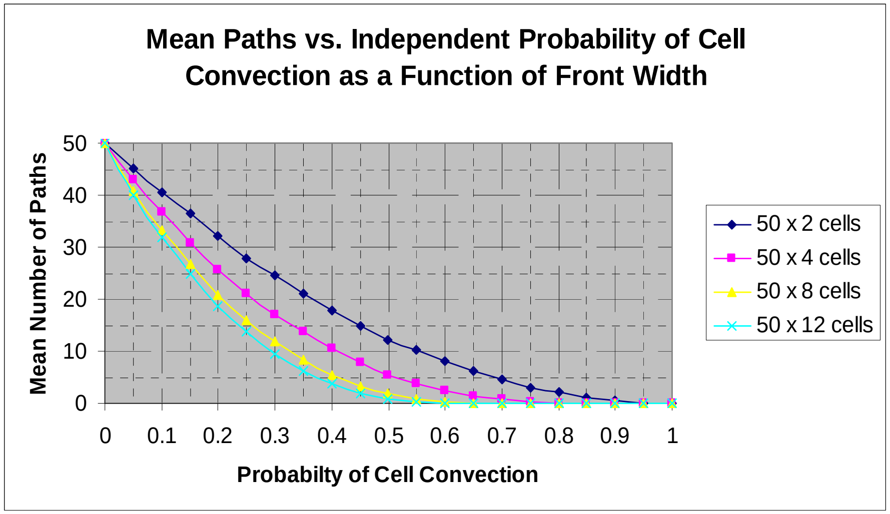
- Model RTVS of CCFP.
- Given an *n x m* grid of cells (10nm squares), each with probability *p* of convection, how many available paths?
- Percolation theory
  + max-flow optim.



Capacity Forecasts

- Uniform increase in mean paths as front length increases

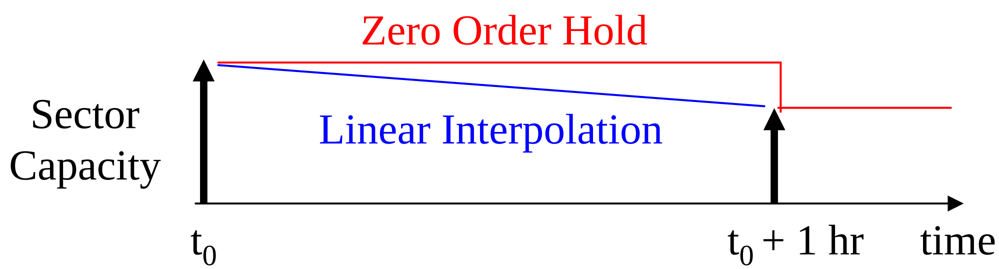




- Uniform decrease in mean paths as front width increases

Capacity Forecasts

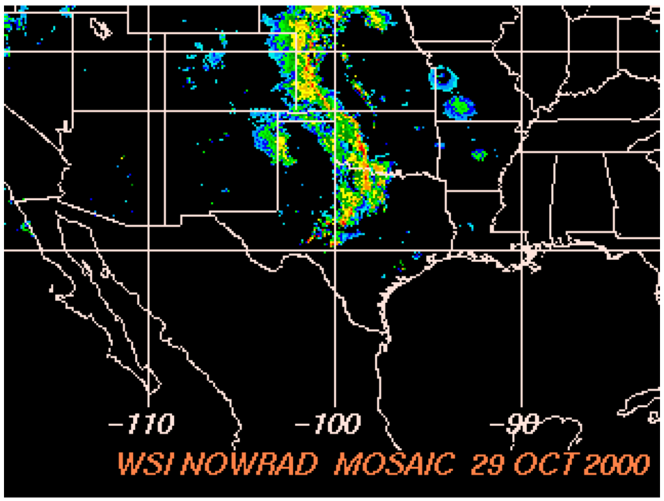
- CCFPs are issued every 4 hours
  - 2, 4, & 6 hour lead time forecasts
- In real-time, weather is dynamic, continuous and observable
- Must approximate this real-time ability via interpolation using hourly NEXRAD images
  - Zero Order Hold or Linear Interpolation

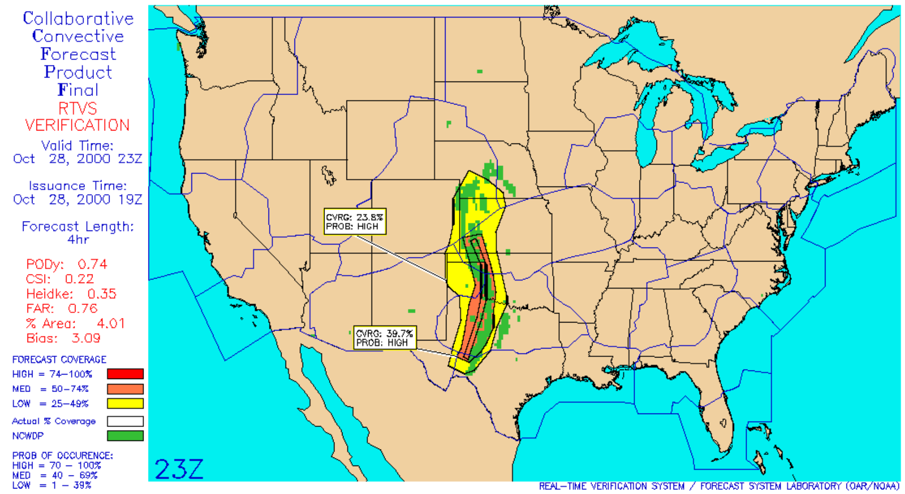


Test Scenarios

- Scenario description
  - Strongly Convective Fronts (October 28, 2000)
  - Inaccurate Forecast (October 16, 2000)
  - Rapidly Developing Convection (October 15, 2000)
  - Weak and Dispersed Fronts (October 21, 2000)

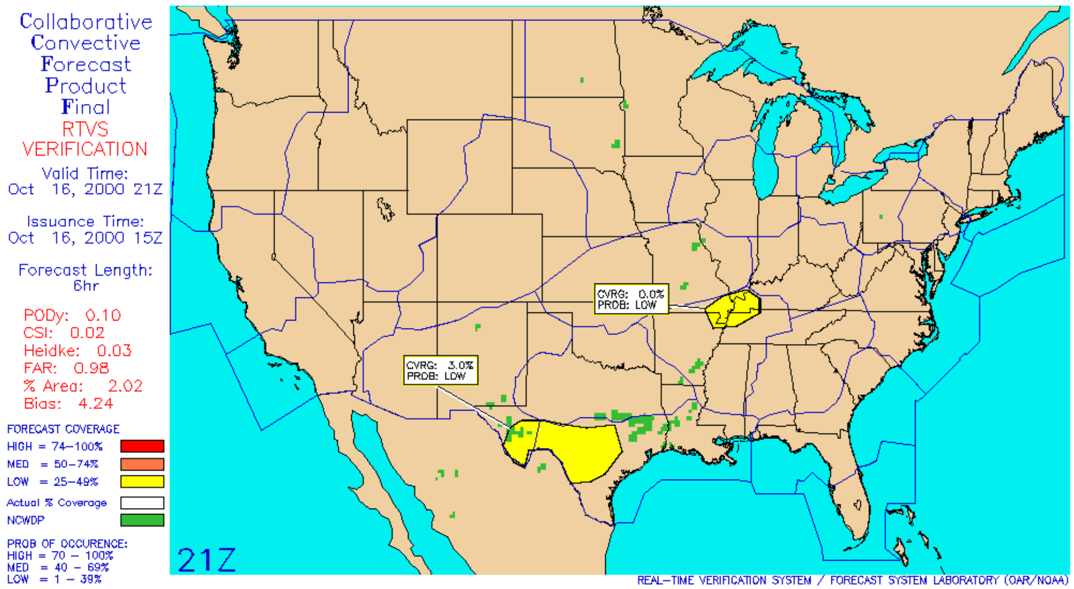
Scenario 1: Strong Convective Front





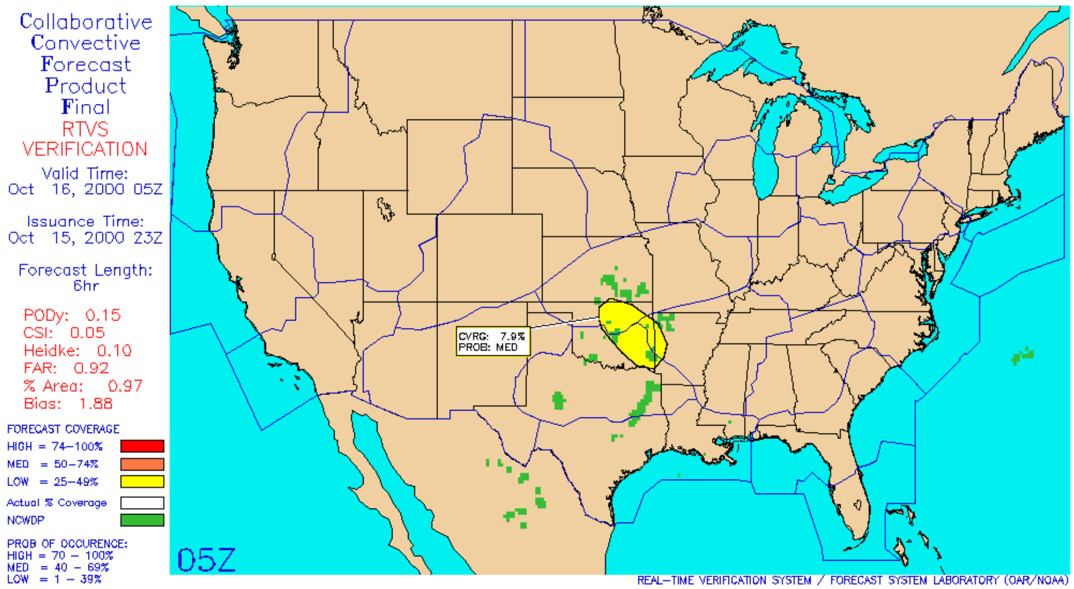
- Strong front sweeps N. Texas and Oklahoma.
- Benchmark: Best-accuracy forecast...
  Best-case performance?

Scenario 2: Inaccurate Forecast



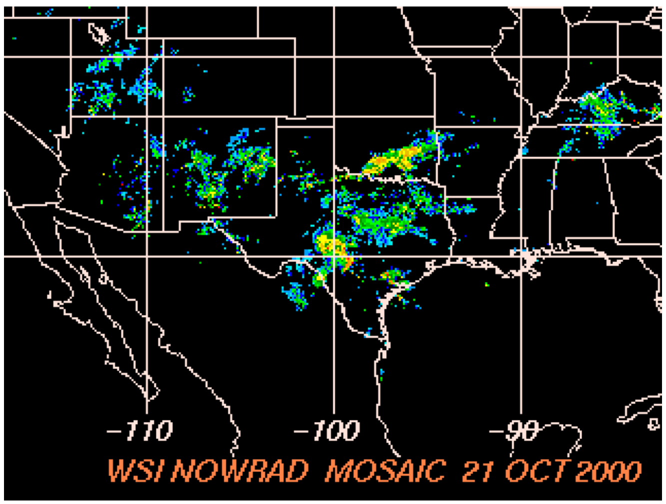
- Very little activity in the forecast area
- Benchmark: Robustness and performance degradation under inaccurate forecast

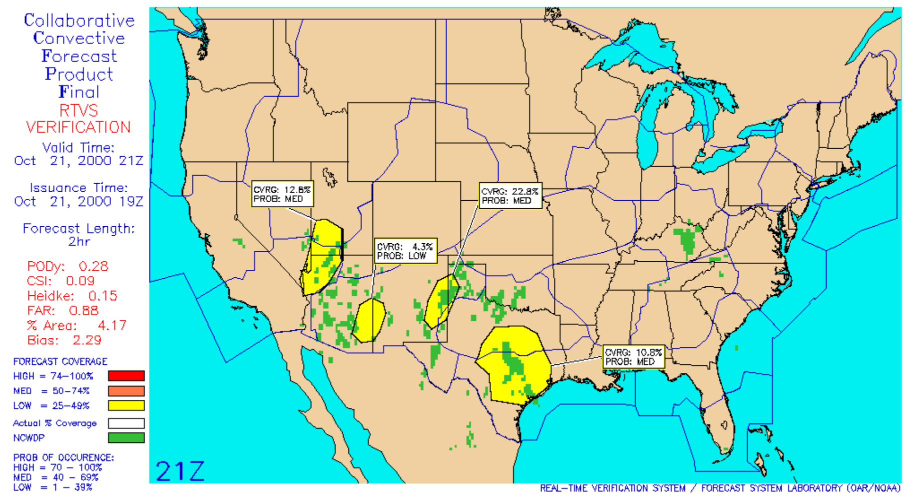
Scenario 3: Rapidly-Developing Convective Activity



- Quick-developing storm activity through N. TX, OK.
  - Radar Loop: 10/15/00, 1300Z – 0200Z (8 AM – 9 PM CST)
- Benchmark: Flexibility/adaptability of routing solutions; dependence on forecast horizon.

Scenario 4: Weak Storm Activity





- Weak “popcorn” storms over NM, TX, OK.
- Benchmark: Sensitivity to noise (weather is low-impact but unpredictable)

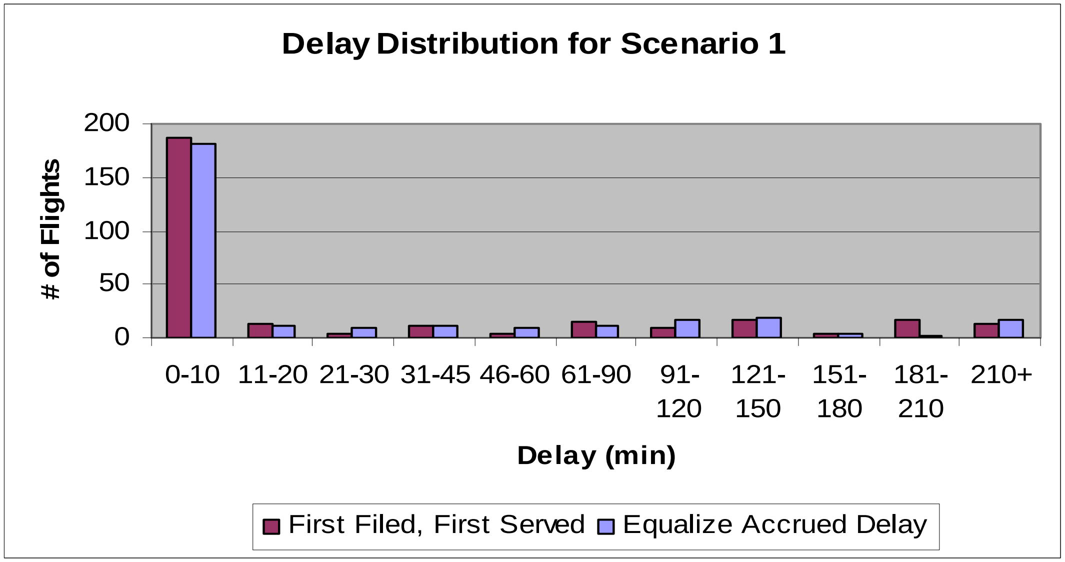
Preliminary Results Qualitative

- Flights departing from FCA unduly held
  - Not as many DOFs as over-flight traffic
  - Segregate traffic into different classes
- Need to provide adequate “buffer” of nominally-constrained sectors around FCA
  - Inability to route around FCAs results in an extreme amount of incurred delay

Preliminary Results Quantitative

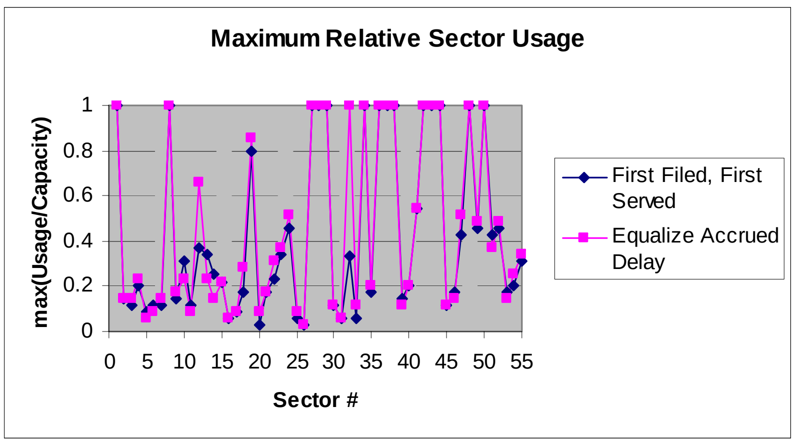
- Scenario 1

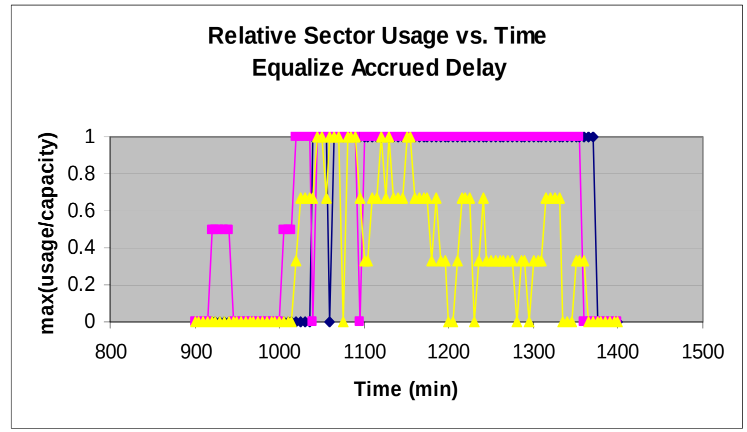
Rationing Scheme	Cumulative Delay
-	sec.
First-Filed, First Served	11830
Equalize Accrued Delay	12140
Global Optimization	5450

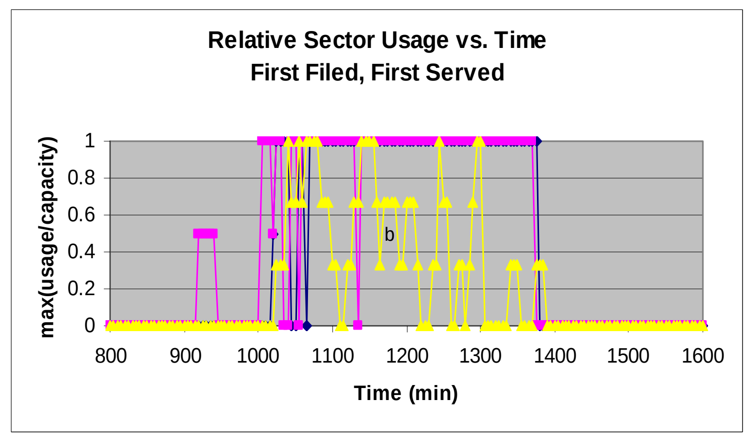


Preliminary Results Quantitative

- Scenario 1







Pending and Future Work

- Analyze remaining scenarios.
- Baseline sector capacities: observed (ETMS) and planned (MAP).
- Per-user costs (database-join against DB-1)
  - Passenger holding delay and delayed connections.
- Examine planning-horizon effects. Fully implement MP-RHC simulation (possible FACET integration).

Pending and Future Work

- Methods for increasing collaboration: Multiple (Filed/Preferred) Routings.

- Investigate user-acceptance issues:
  - "Fairness" via Completely Biased heuristic.
  - Site-visits to ZBW.
  - Dynamic stability of plans.

- Incorporate state-of-the-art Nowcasting ability
  - Growth & Decay Storm Tracker
  - Advection Interpolation and Extrapolation