A Trajectory-Based Probabilistic TFM Evaluation Tool and Experiment

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Sensis Corporation

ICNS Conference 2006

Baltimore, MD

May 3, 2006

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Seagull Technology Center

Detect the Difference

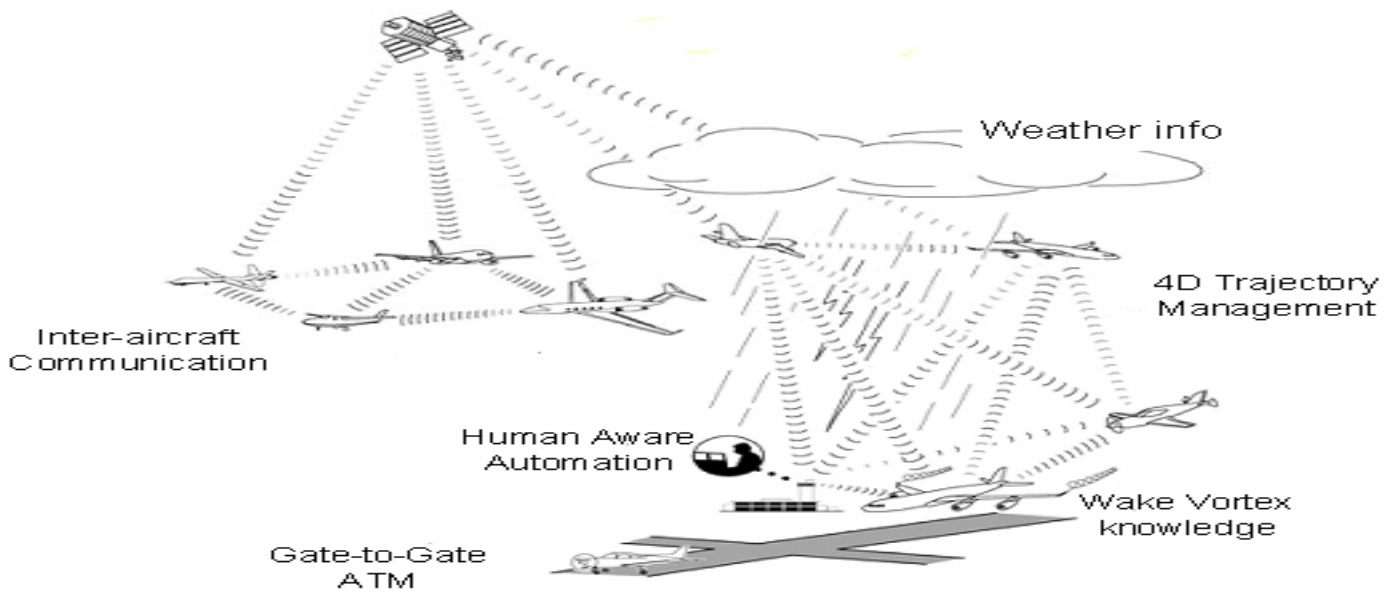
Presentation Outline

- Motivation
- Concept overview
- Modeling details
- Preliminary test results
- System comparisons
- Conclusions

Motivation

Motivation

- Planning for the future
  - High demand growth in past two decades
    - Expected to continue
  - Future strategies should account for heavy weather days



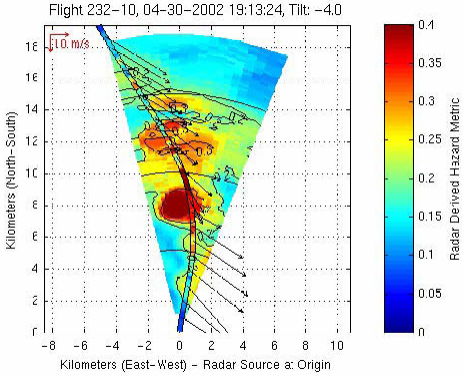
Graphic courtesy of Mike Bragg, Univ of Illinois

Motivation (continued)

- Emerging technologies and strategies for the future
  - Tactical and strategic

Emerging Strategies

- Tactical
  - Flight deck / aircraft
    - Improved sensors
      - Turbulence prediction and warning system (TPAWS)
        - » Turbulence detected from second moment of reflectivity
        - » 25 – 40 nmi, but does not detect CAT
      - Laser radars (LIDAR)
        - » Short range, detects CAT
    - Modify flight control system for reduced gust response
      - Manage the aircraft plunge response to turbulence



Emerging Strategies

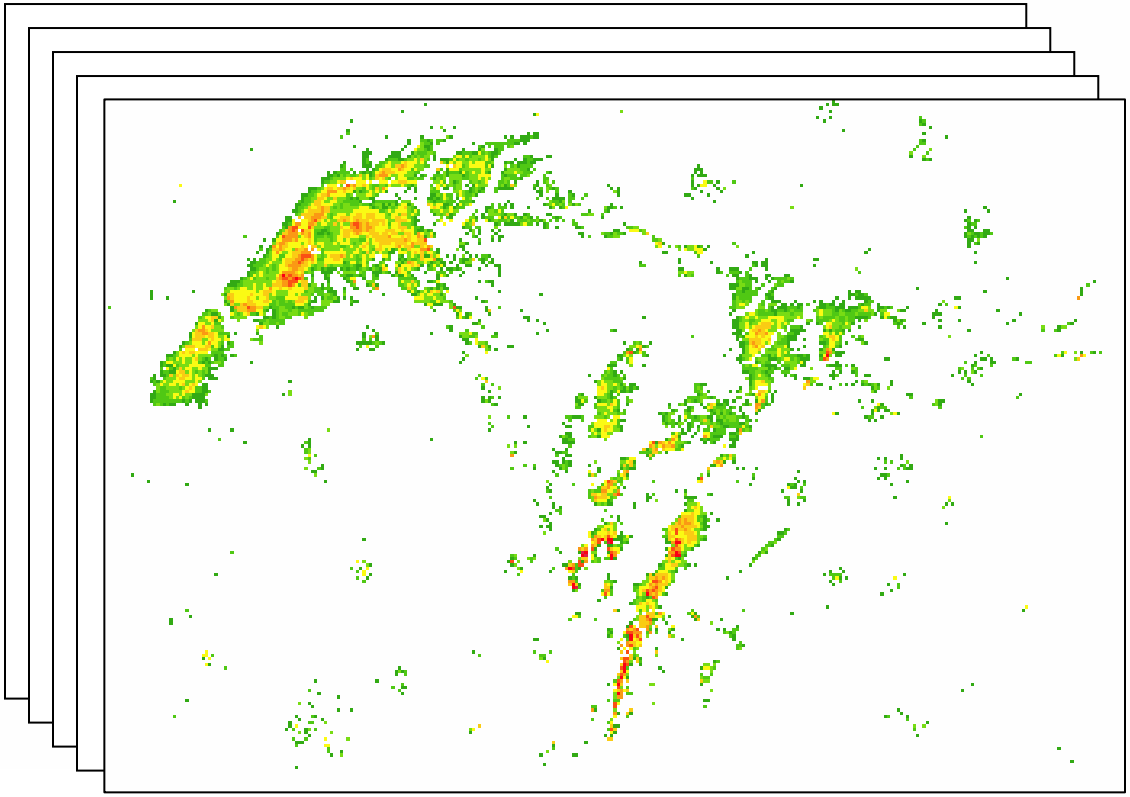
- Tactical (continued)
  - Traffic control
    - Ground- or air-based decision support tools
      - For enhanced weather vectoring
      - Example: AAC for advanced CD&R capabilities

Emerging Strategies

- Strategic
  - Meteorological products
    - Improved sensors, collection systems, reporting systems, forecasting methods
  - Traffic flow management (TFM)
    - Probabilistic TFM
      - TFM and ATM decision support tools based on probabilistic meteorological products

Using Met Products

- Here is your 4D forecast



  - It's probably wrong ...

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Emerging Strategies

- There are many tactical and strategic improvements on the way
  - How to use them all together?

Development of ProbTFM Tool

- Trajectory model
  - Generate 4D trajectories
- Future user demand model (AvDemand)
  - Traffic level escalation, business model shifts, fleet mix shifts, schedule generation
- Airspace modeling
- Weather modeling
  - Truth weather and nowcast / forecast
- TFM and ATC models
  - Delay, rerouting
  - CD&R, storm vectoring
- AOC cancellation model (next phase)

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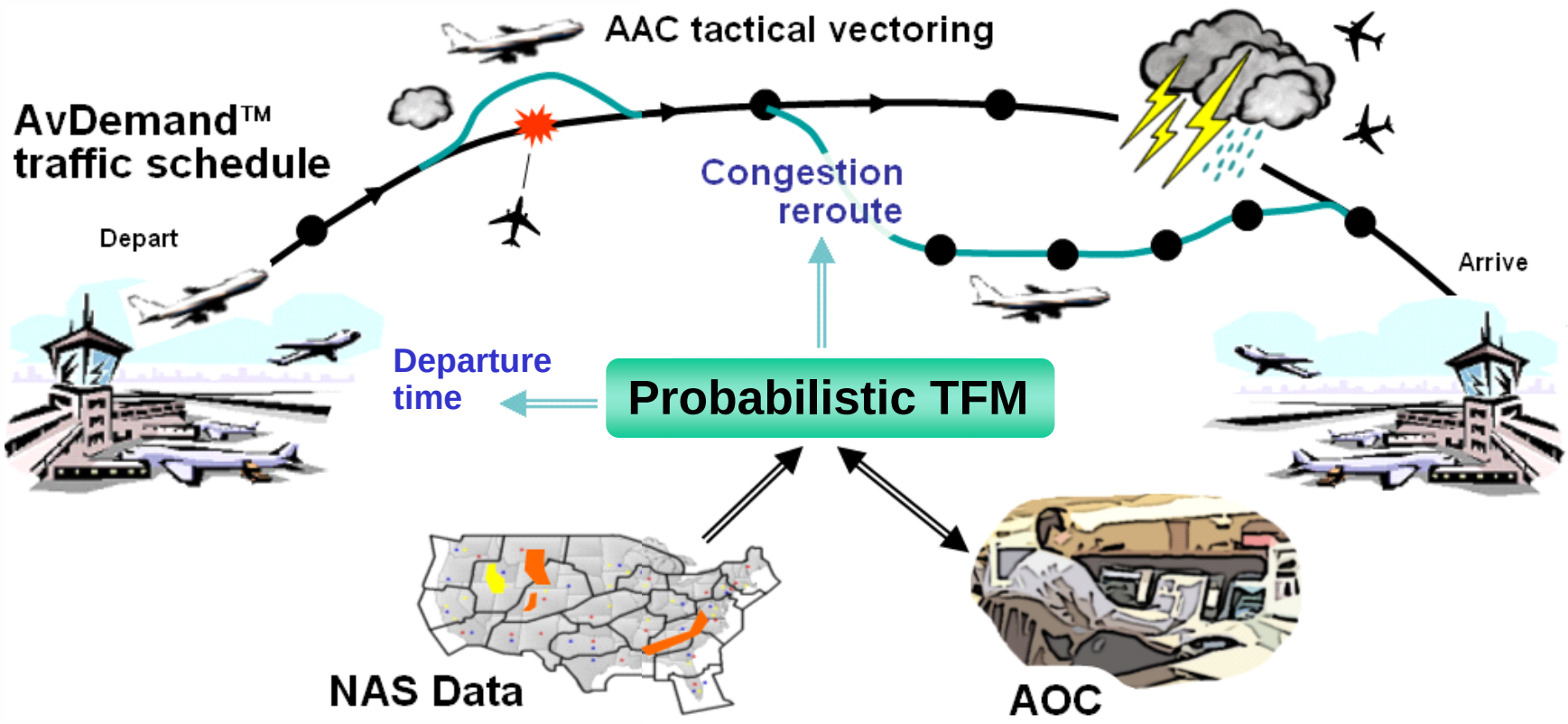
Probabilistic TFM



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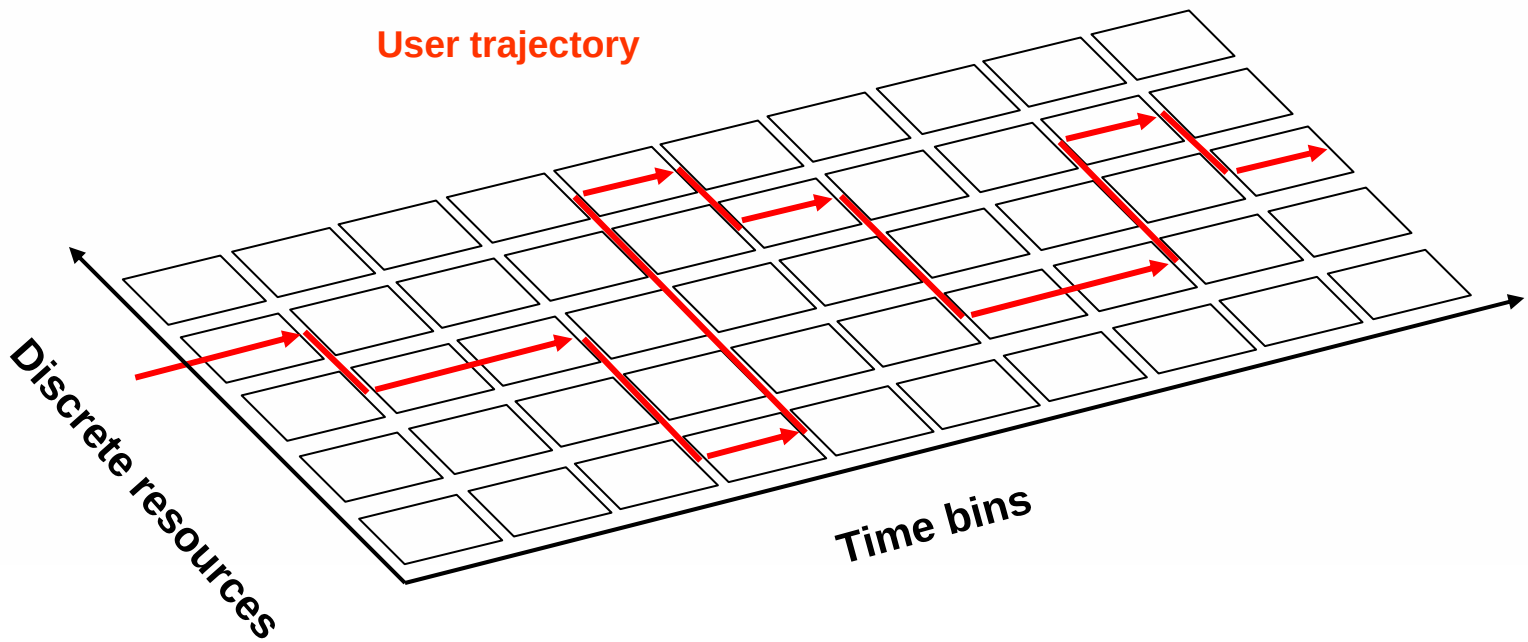
Concept overview

Ensemble Path Planning

- Single trajectory path planning
  - Optimize *f* (time, fuel, etc)



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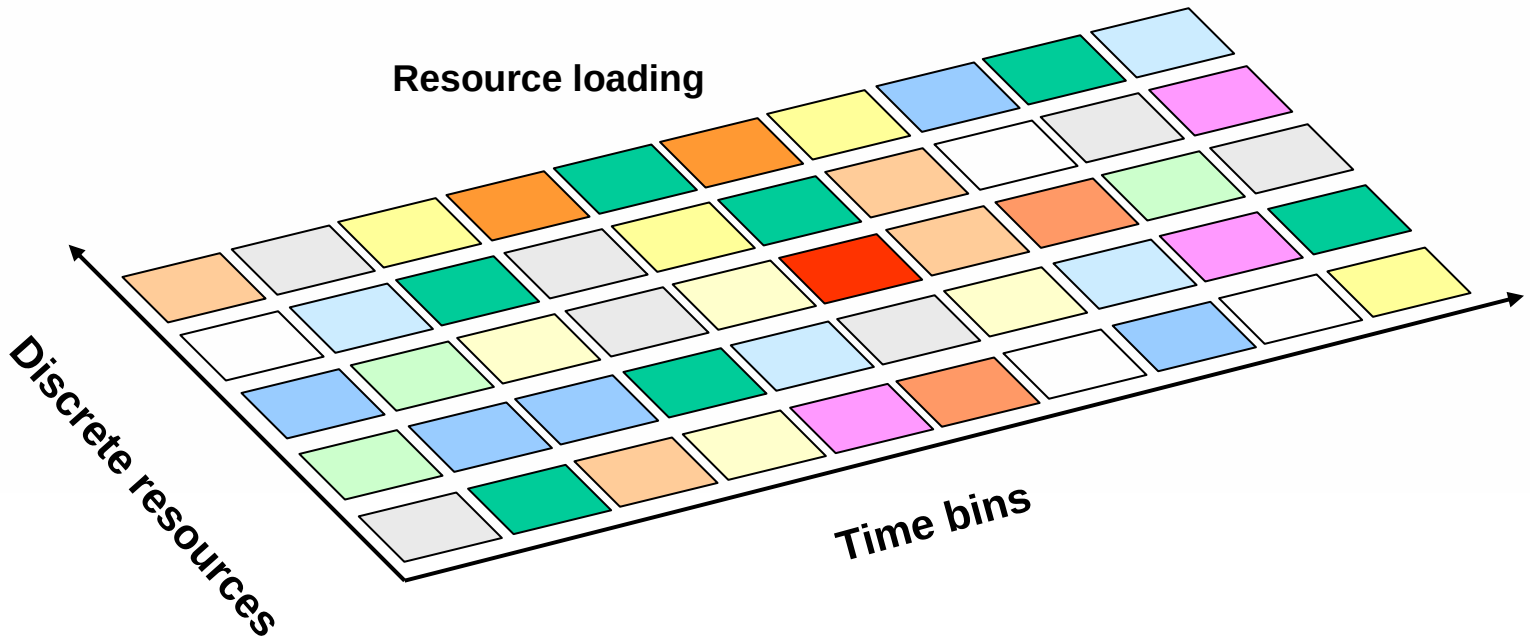
Ensemble Path Planning

- Ensemble path planning
  - Optimize ensemble *f* (time, fuel, etc)



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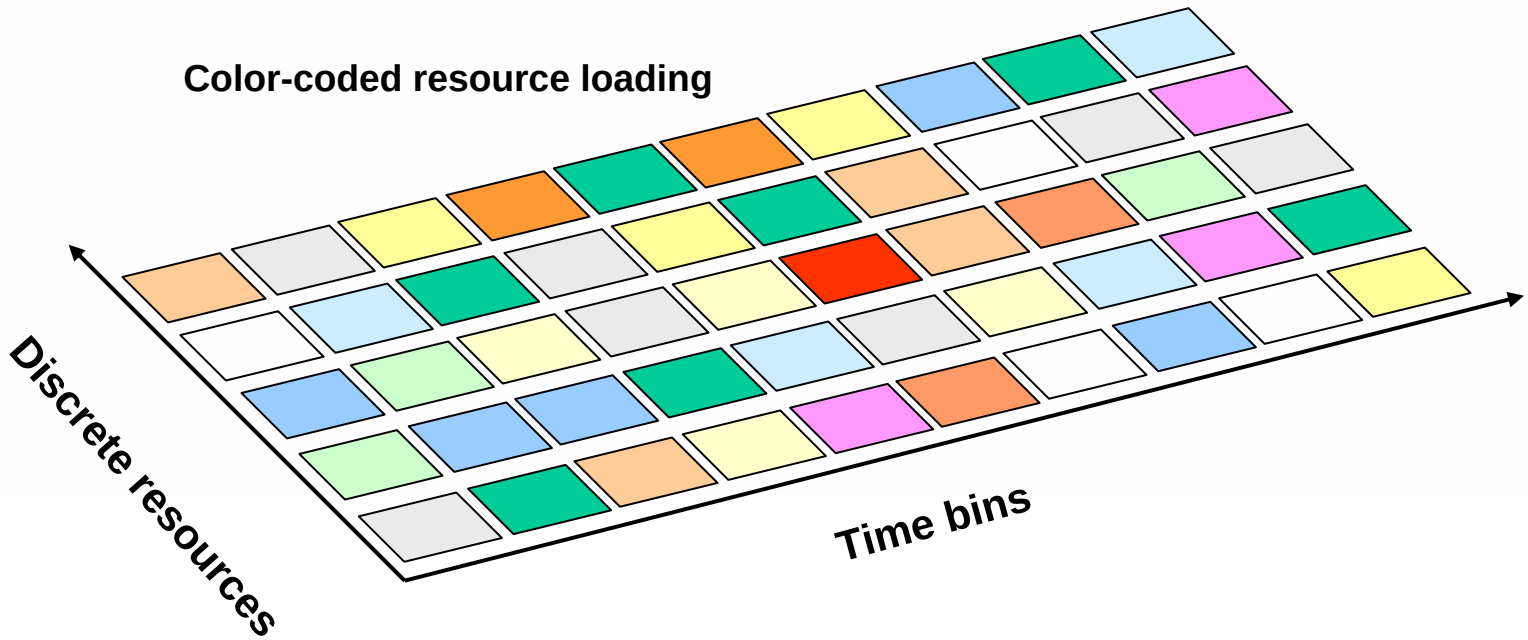
Ensemble Path Planning

- Ensemble path planning
  - Optimize ensemble *f* (time, fuel, etc)
  - Capacity constrained resources => congestion



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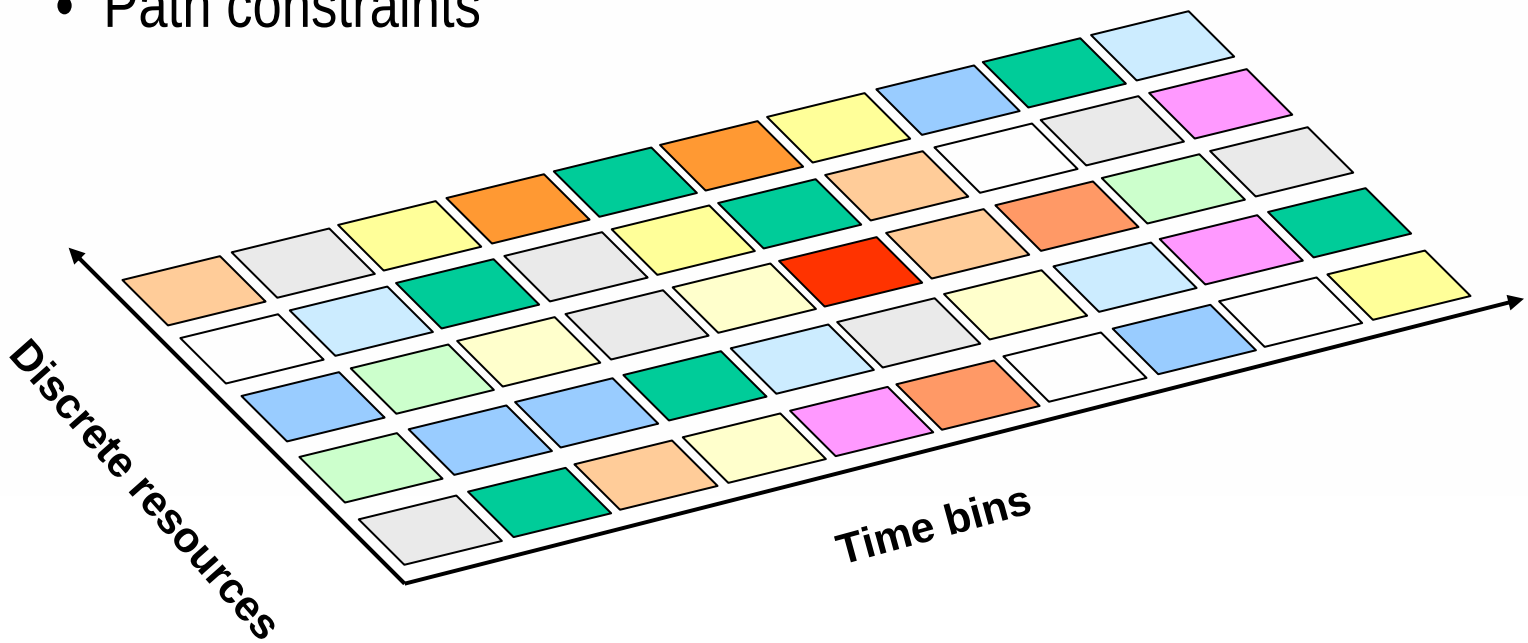
Ensemble Path Planning

- Ensemble path planning
  - Optimize ensemble *f* (time, fuel, etc)
  - Capacity constrained resources => congestion
    - Uncertainty in congestion forecast
    - Path constraints



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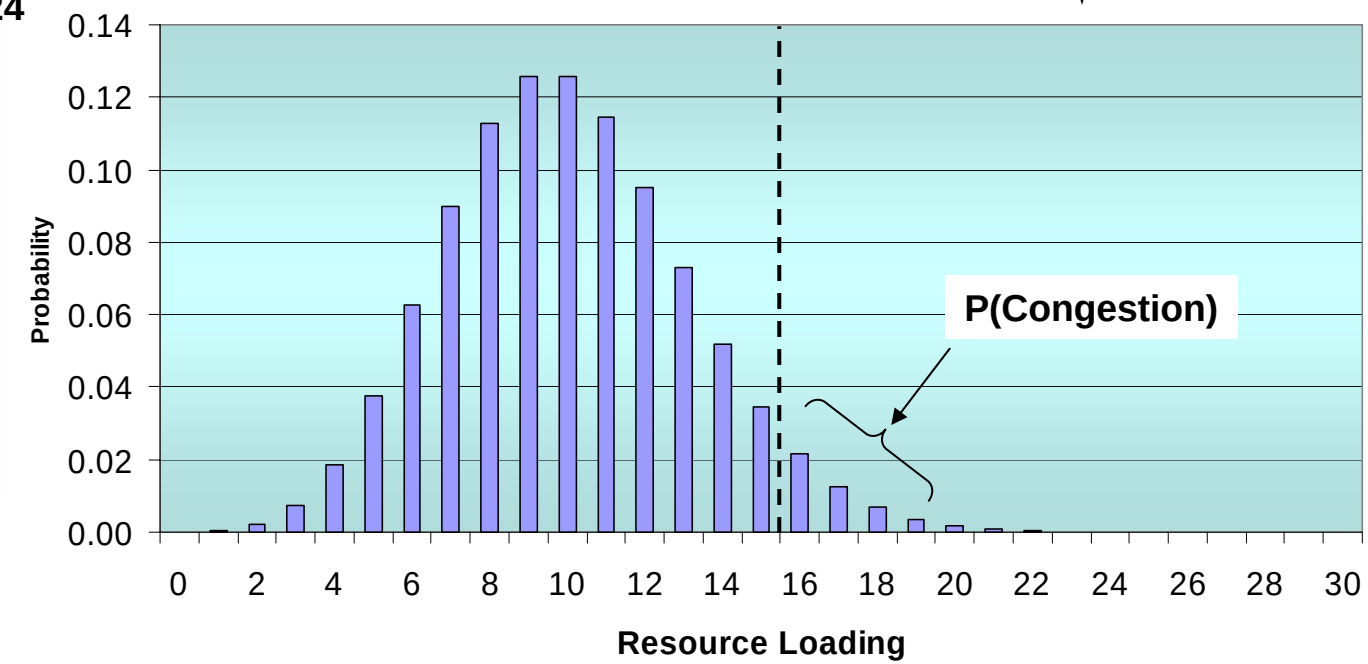
Ensemble Path Planning

- Assume
  - Trajectories uniformly distributed across the resources
  - Resource loading is a binomial distribution

Resources: 100 , P(resource) = 0.01, capacity = 15
Trajectories: 3000, 8 time points
Total time points: 24
Mean loading: 10



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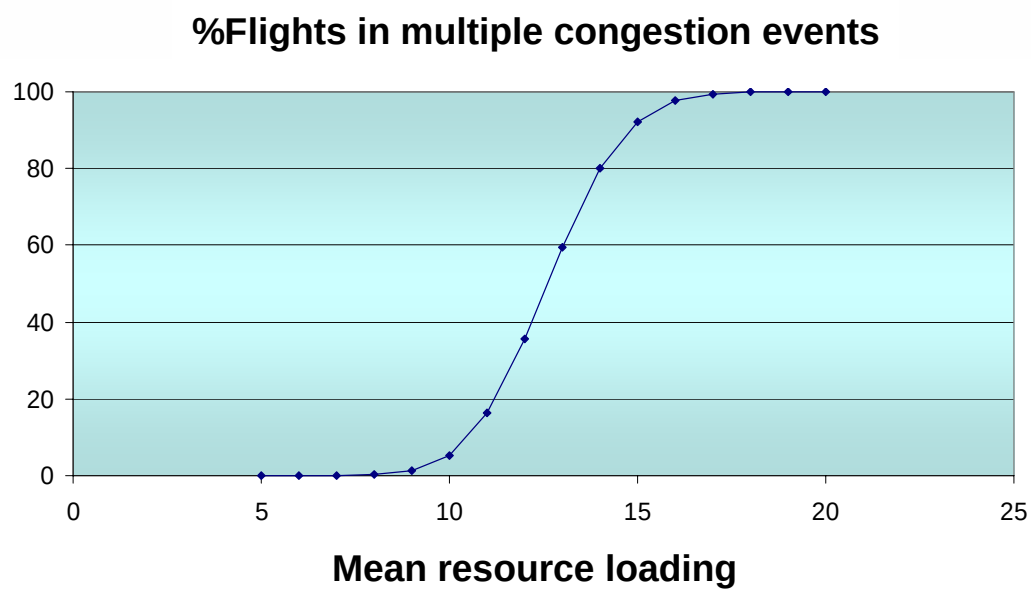
Ensemble Path Planning

- Flights in multiple congestion events
  - Increases dramatically as mean loading approaches capacity



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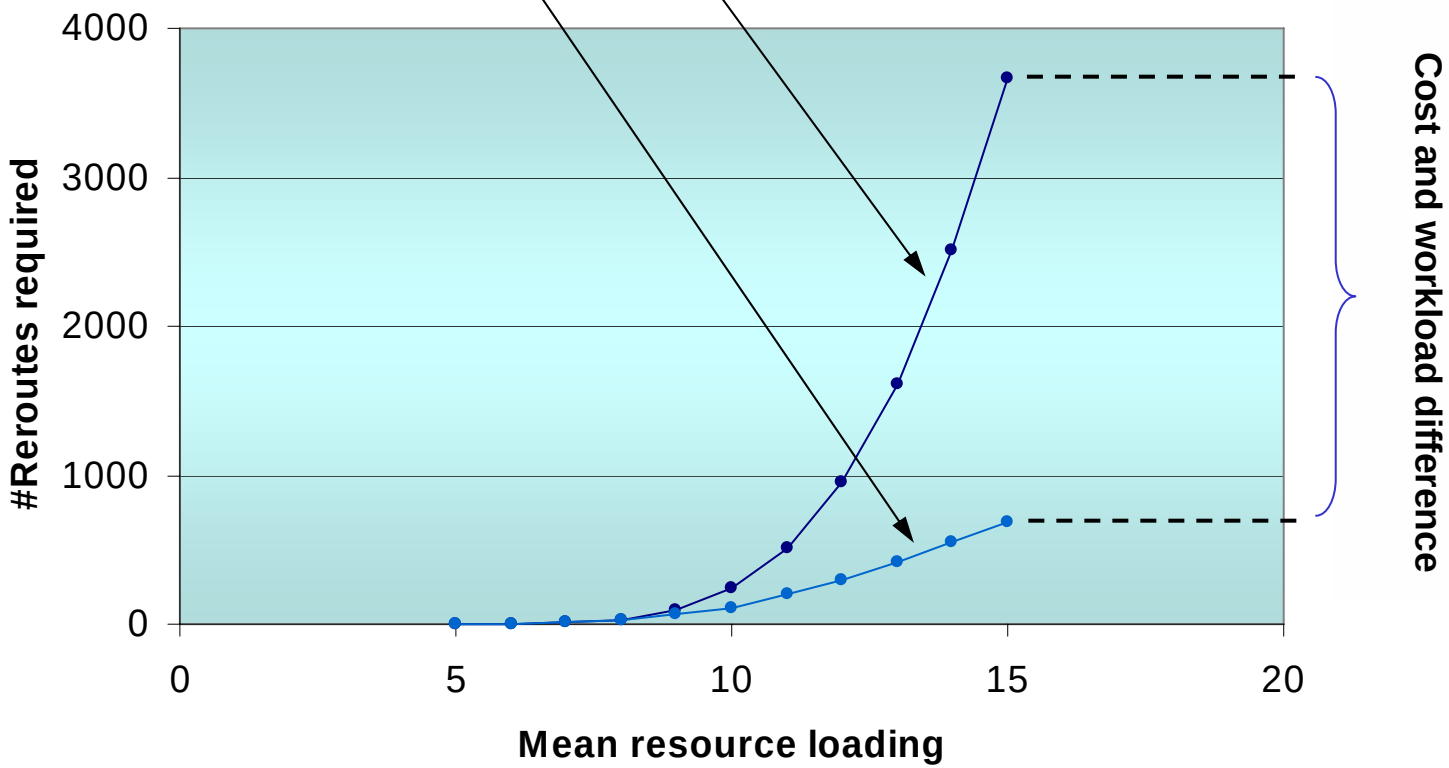
Ensemble Path Planning

- Bounding strategies
  - Manage by airspace
  - Manage by trajectory



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Ensemble Path Planning

- Suggests an ensemble path planning strategy
  - Probabilistic traffic flow management by trajectory
  - Flights ranked by congestion level
  - Gate delays and reroutes are used to reduce congestion across the entire trajectory
  - A possible solution to the equity problem
    - Those flights that contribute the most to congestion are managed to reduce system congestion.

Modeling Details

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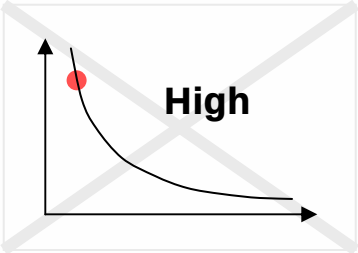
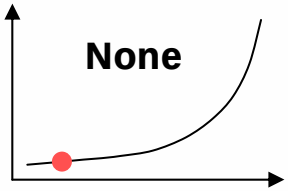
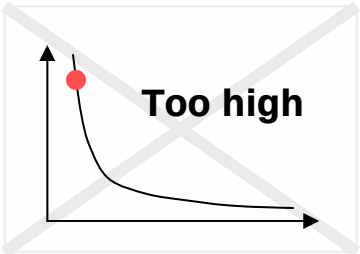
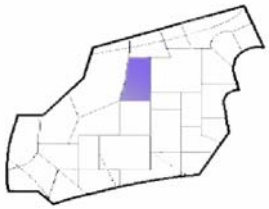
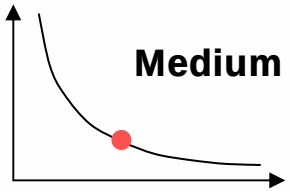
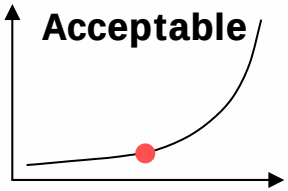
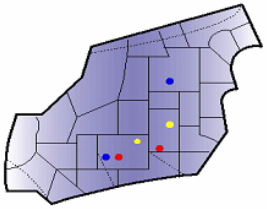
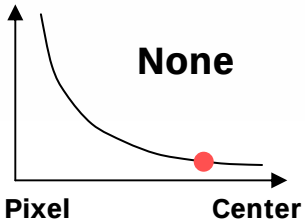
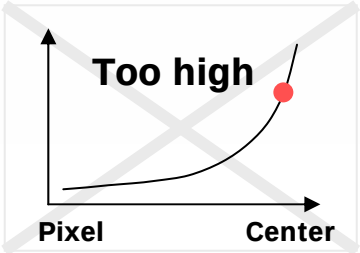
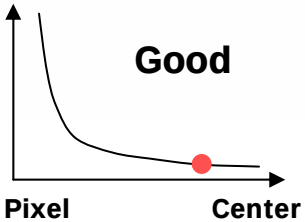
Strategic Grid Size

Grid size	Spatial correlation	Smoothing / blurring	Compute resources
Pixel <1 nmi			
 Sector ~10s nmi			
 Center ~100s nmi	 *Grid size*	 *Grid size*	 *Grid size*

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Airspace Capacity

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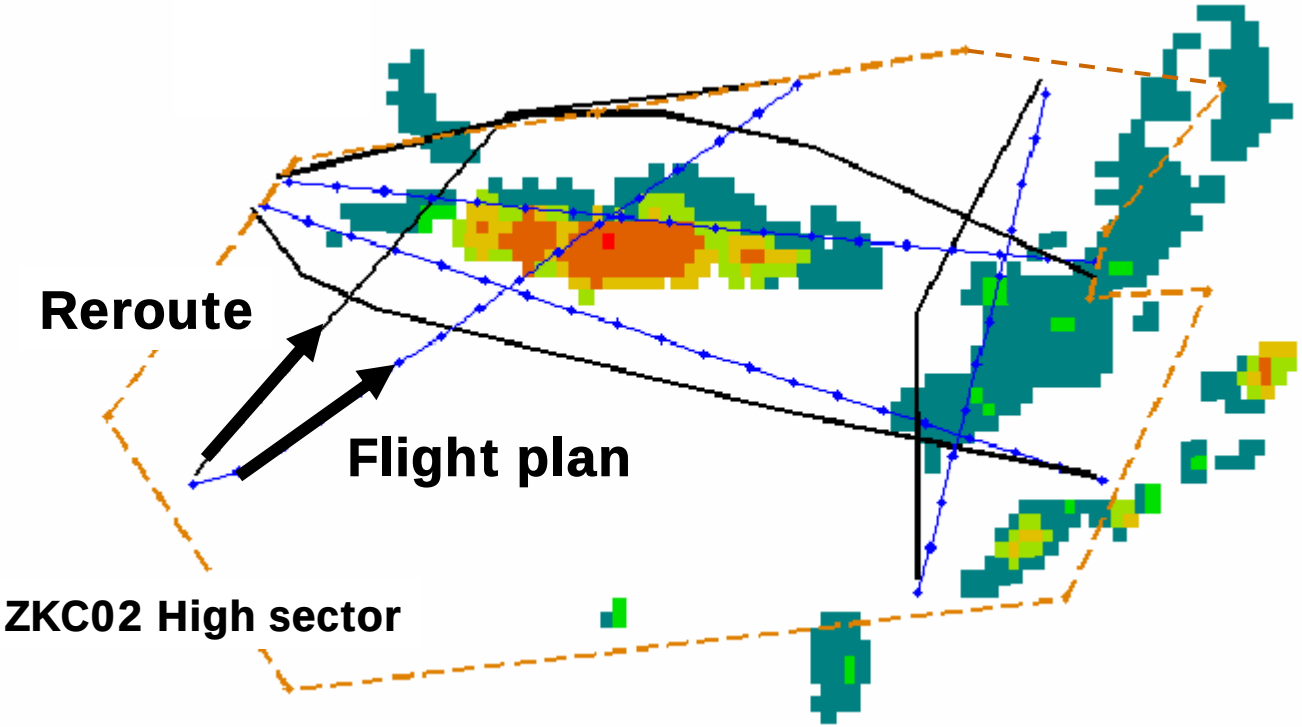
Trajectory-based Weather Impact

Analyze specific trajectory, not just flow through sector

Analyze Wx impact on the specific trajectory



Count a route as unavailable only if reasonable reroutes are also unavailable

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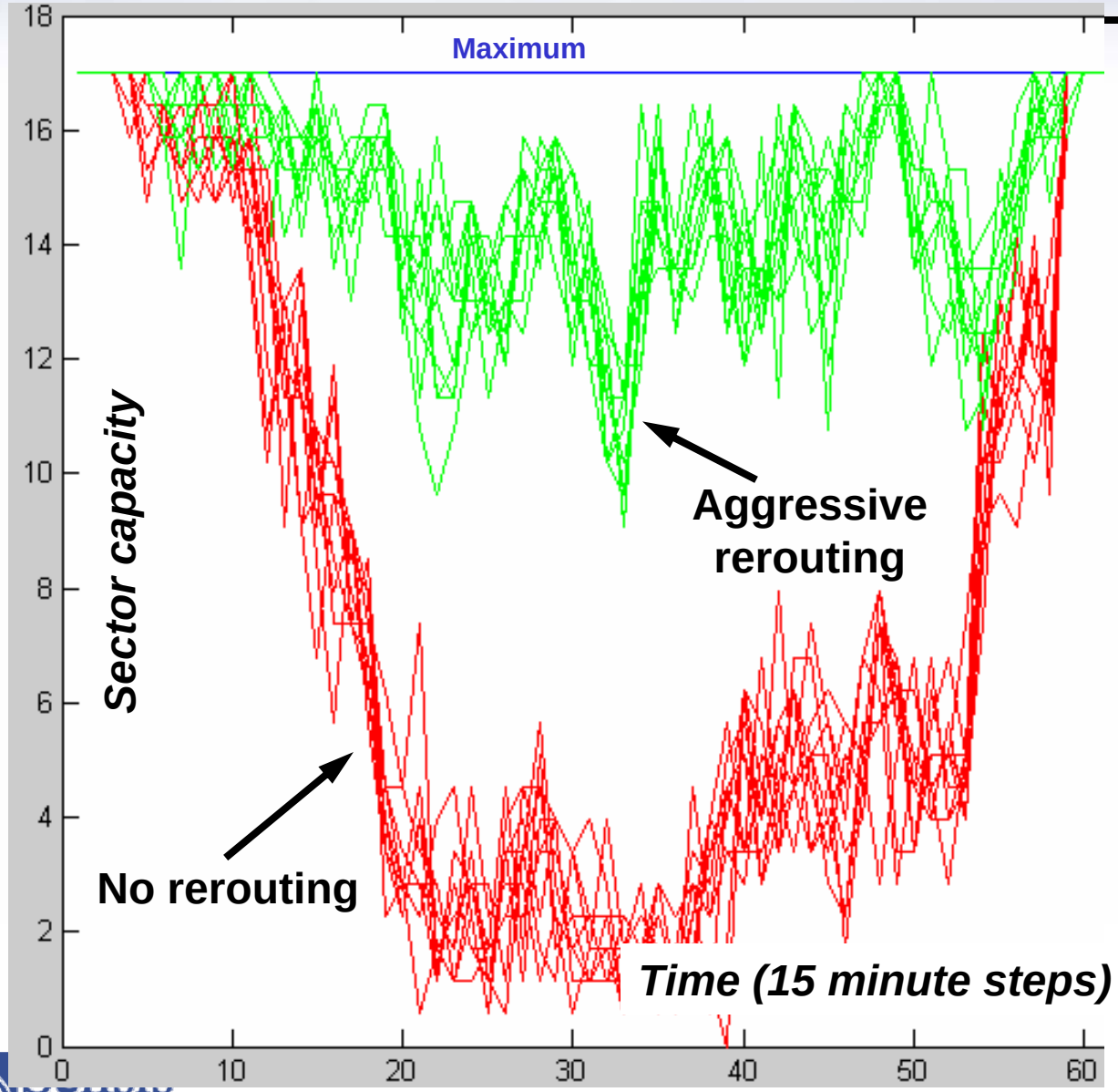
Sector Capacity Nowcast

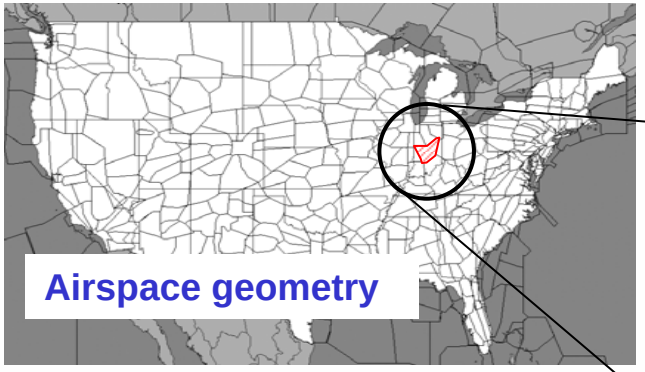


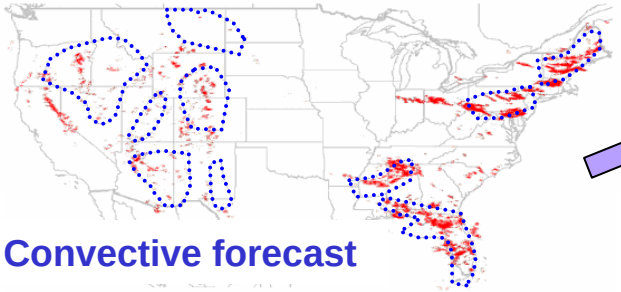
Example MSC' results for May 10, 2004. Sector ZKC02. Randomly select 30 flights that transit the sector and compute upper and lower bounds. Repeat this 10 times to check for convergence.

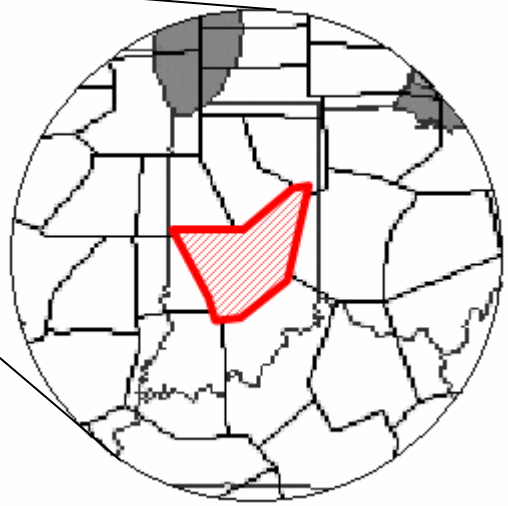
Result: Good convergence found. 30 flights selected at random reproduce upper and lower bound estimates with low variance.

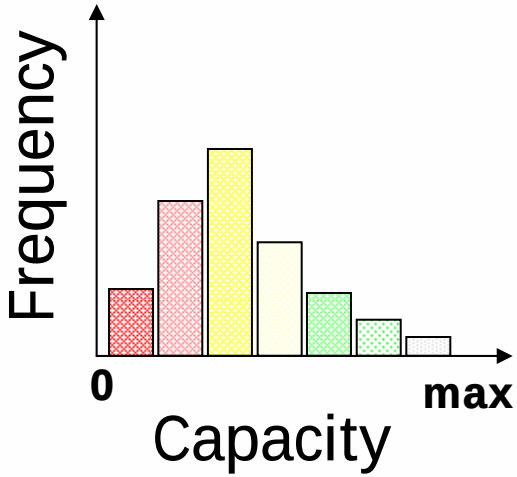
Sector Capacity Forecast

- Result: A forecasted sector capacity probability distribution function (PDF)
  - For all sectors, all time horizons, all time slots









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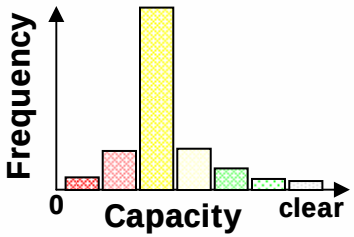
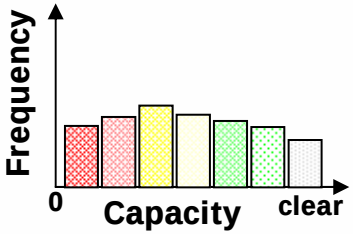
Computing Airspace Capacity Probability

Sector Capacity Probability



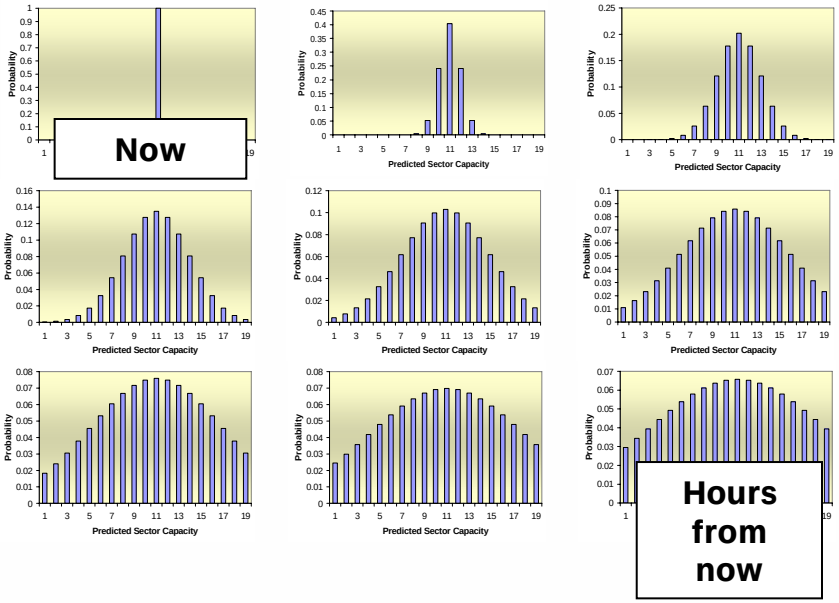


- Short look-ahead time
- Accurate storm forecast

- Long look-ahead time
- Inaccurate storm forecast

Many factors impact PDF shape

Sector Capacity Probability



Capacity uncertainty grows dramatically with length of look-ahead

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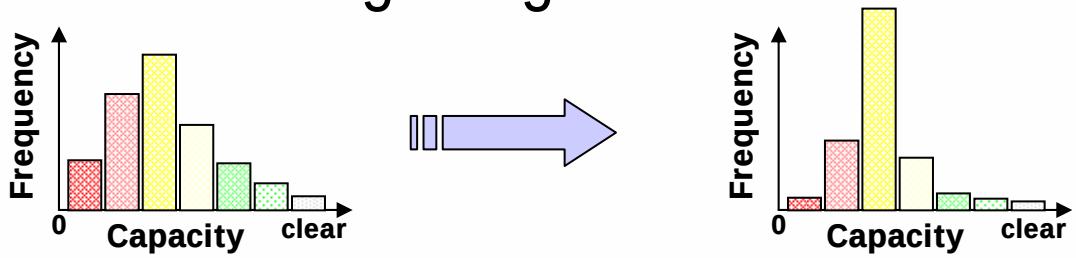
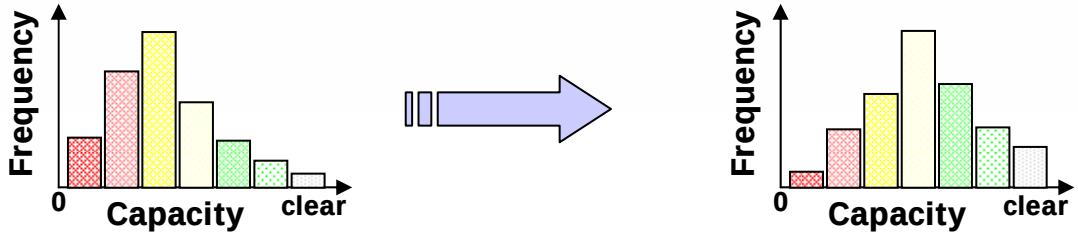
Airspace Capacity Parameters

- Input settings for quality of storm forecast and quality of ATC vectoring
  - Improved forecasts give tighter distribution



  - Improved tactical shifts distribution to right



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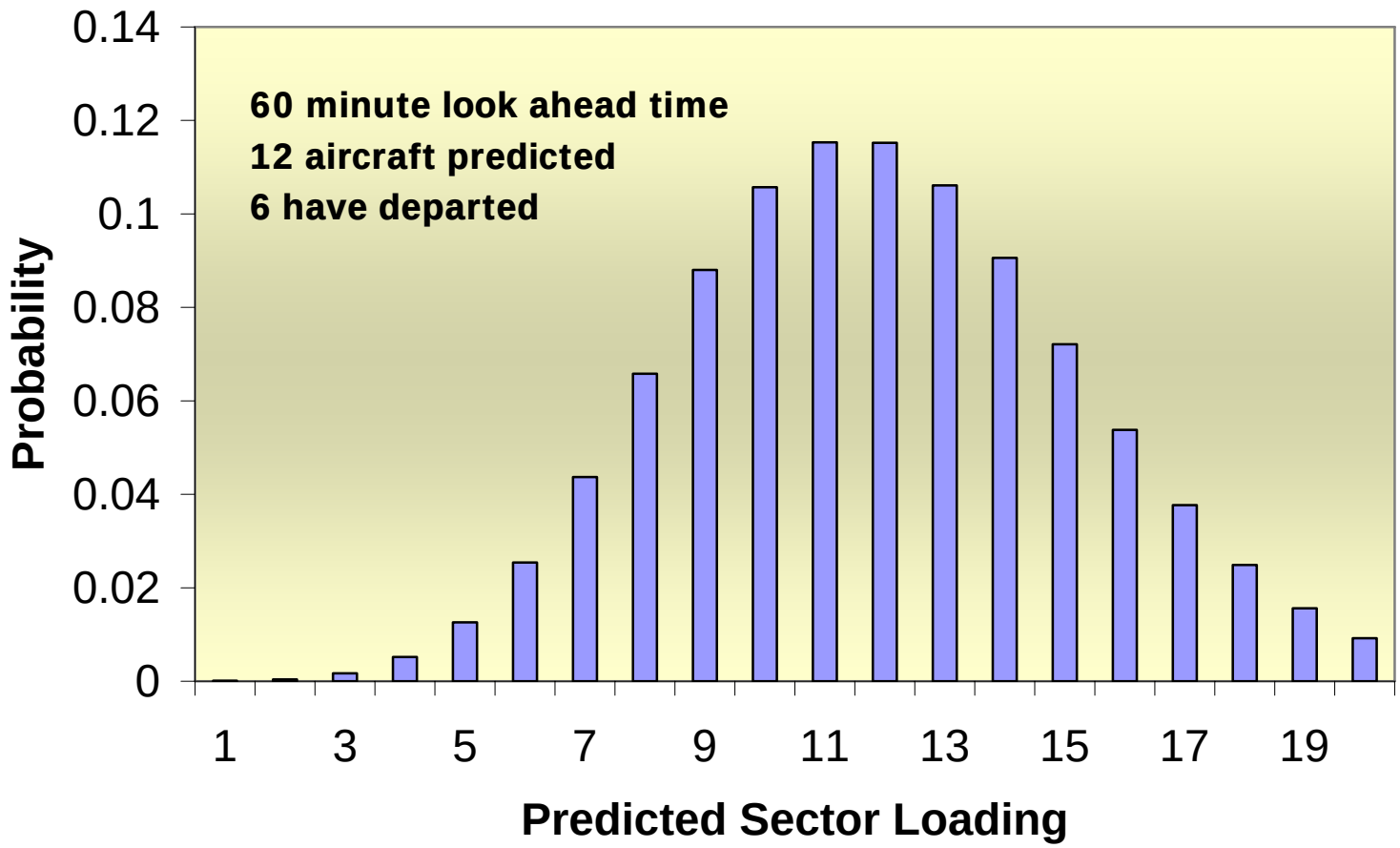
Sector Loading

Sector Loading PDF

- Difficulty in forecasting the NAS
  - The NAS includes many adaptive agents, often thwarting long range predictions and action plans
    - Many causal factors
      - Including adaptive, multiple decision makers
    - Chaotic nature
    - Inaccurate control actions and observability
  - <u>Major sector loading error sources</u>: gate departure time and en route wind forecast

Example Sector Loading PDF



C. Wanke, L. Song, S. Zobell, D. Greenbaum, and S. Mulgund, "Probabilistic Congestion Management," 6th USA/Europe Seminar on Air Traffic Management Research and Development, June 27, 2005.

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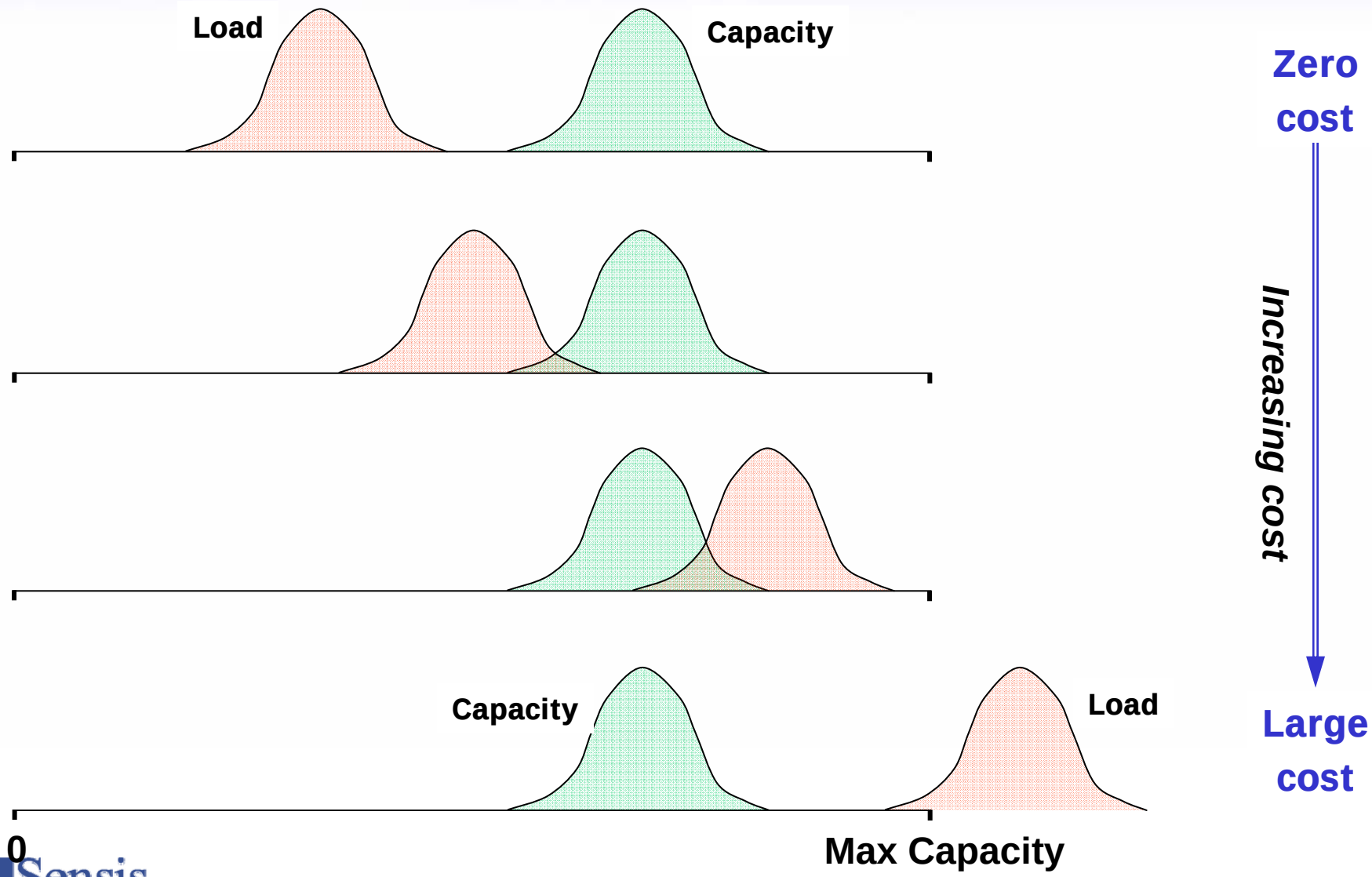
Sector Congestion Cost

Sector Congestion Cost



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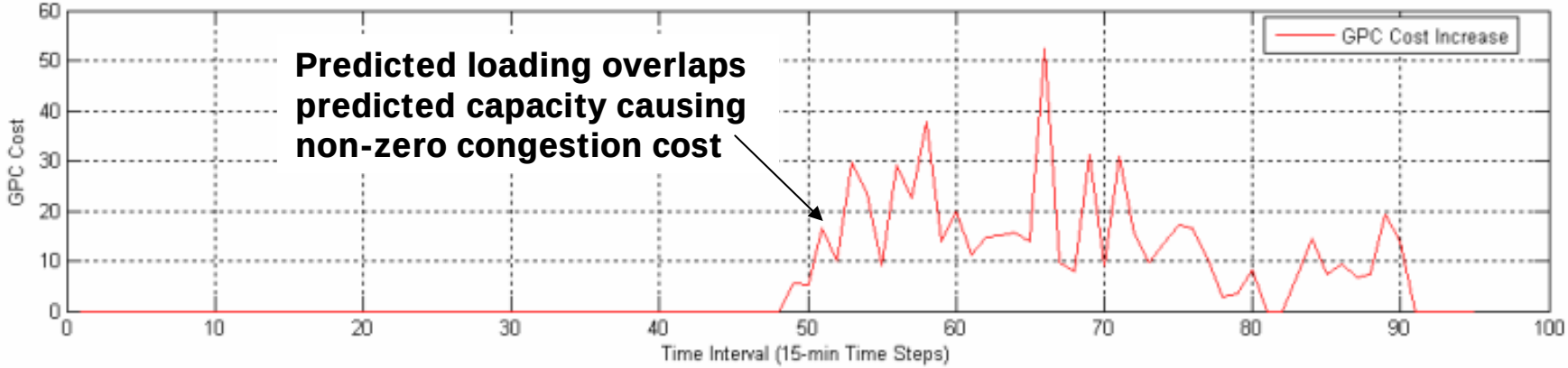
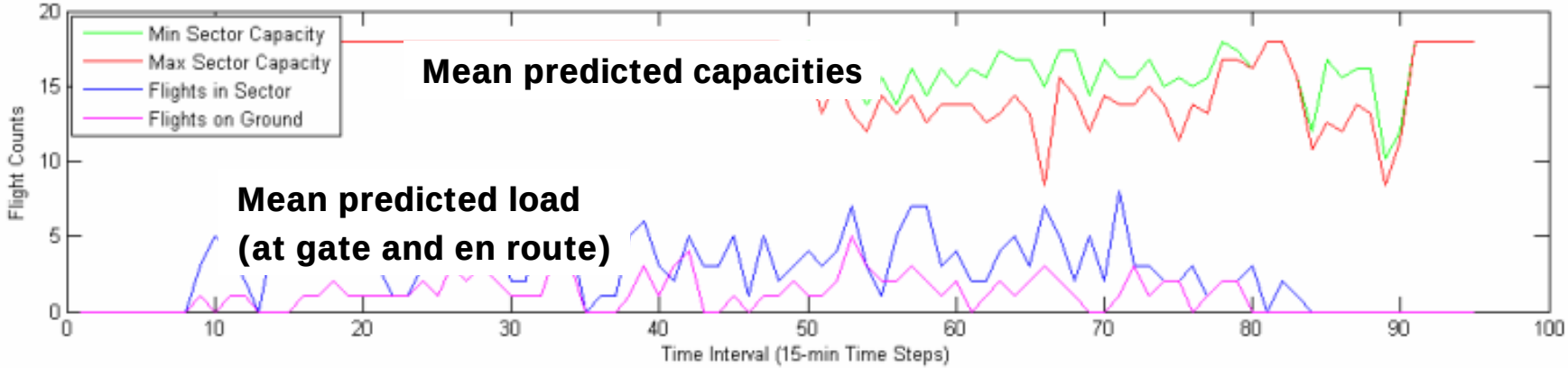
Congestion Cost Time History





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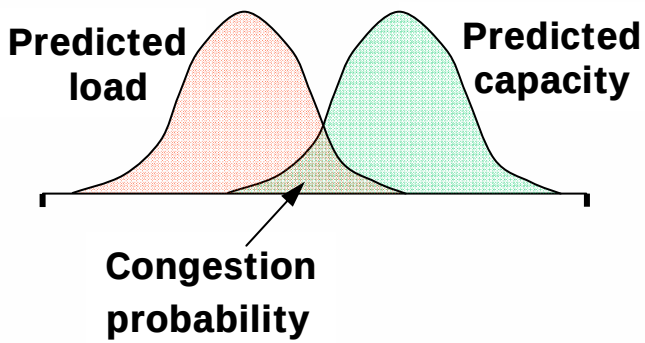
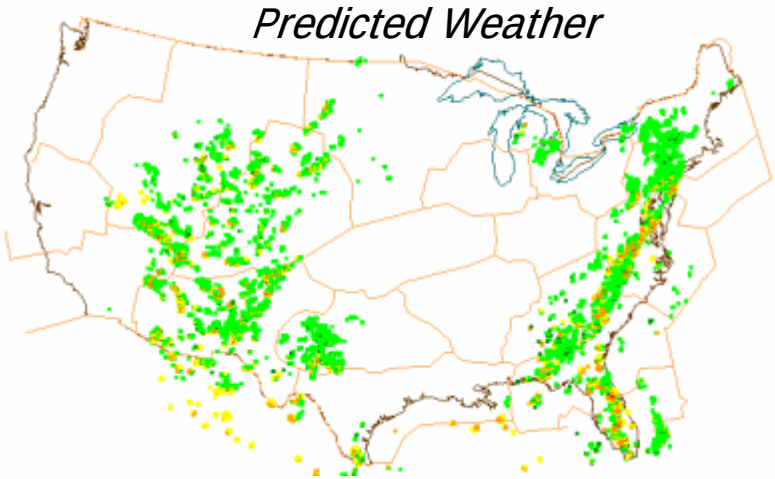
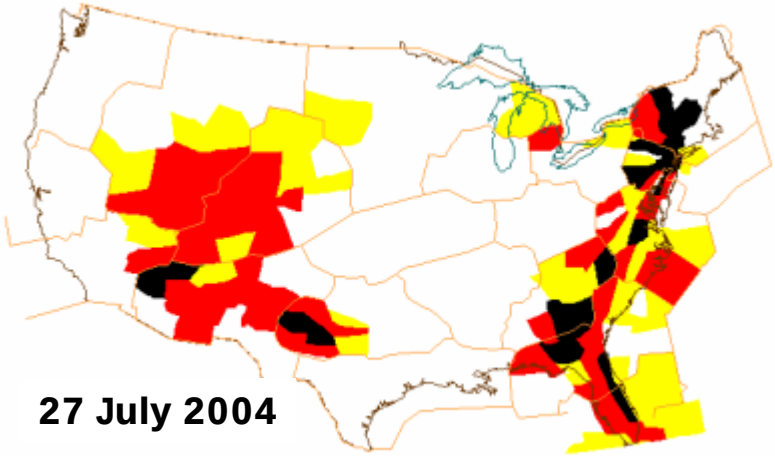
Congestion: Load vs Capacity



Predicted Weather



Congestion map: a combination of the predicted weather impact and predicted traffic



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Preliminary Test Results

Using 27 July 2004 Weather Data

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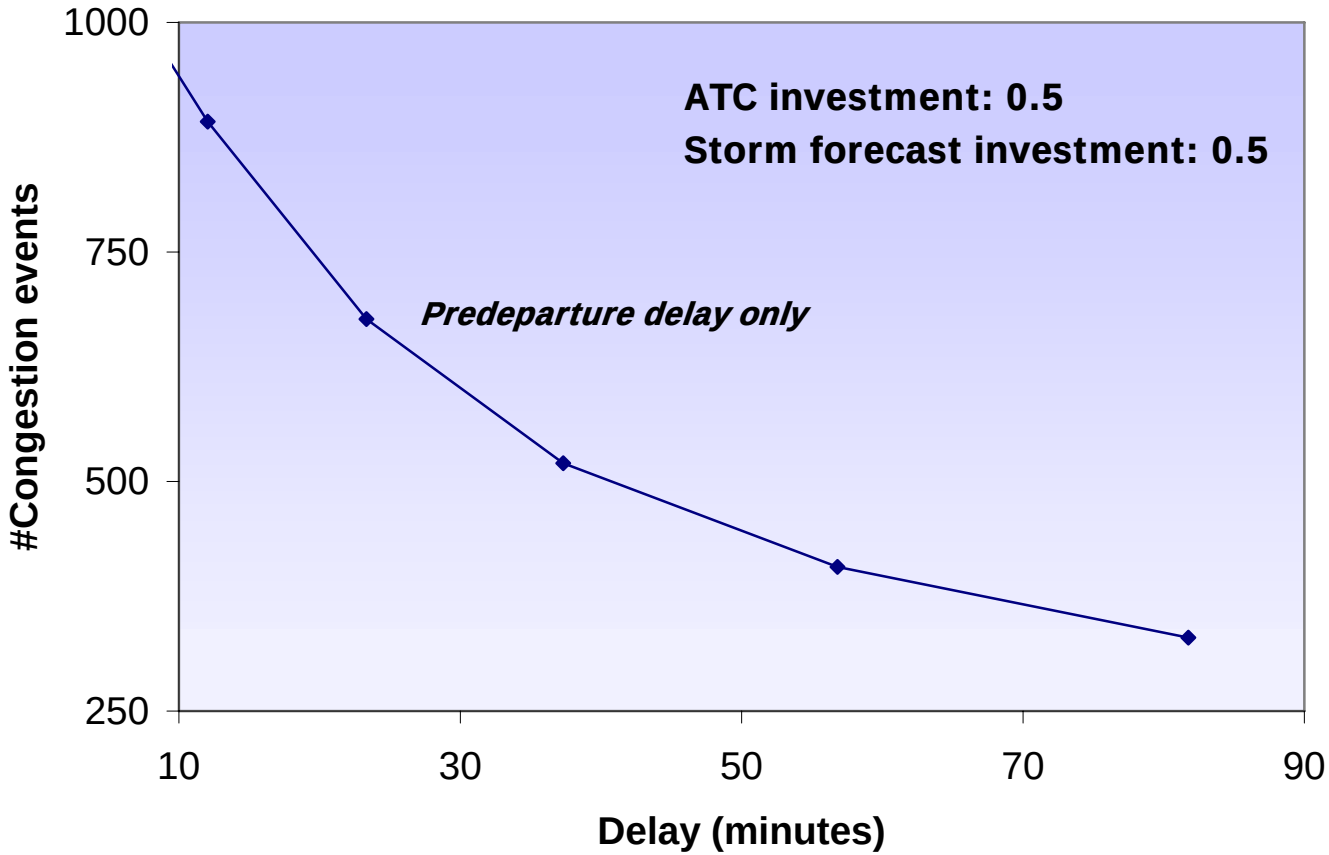
Initial Results

- Evaluate NAS performance
  - Congestion and delay performance metrics
  - Use gate delay and rerouting mechanisms
- As a function of storm forecasting and ATC investments
  - Normalized as parameters ranging from 0 to 1

Congestion/Delay Tradeoff



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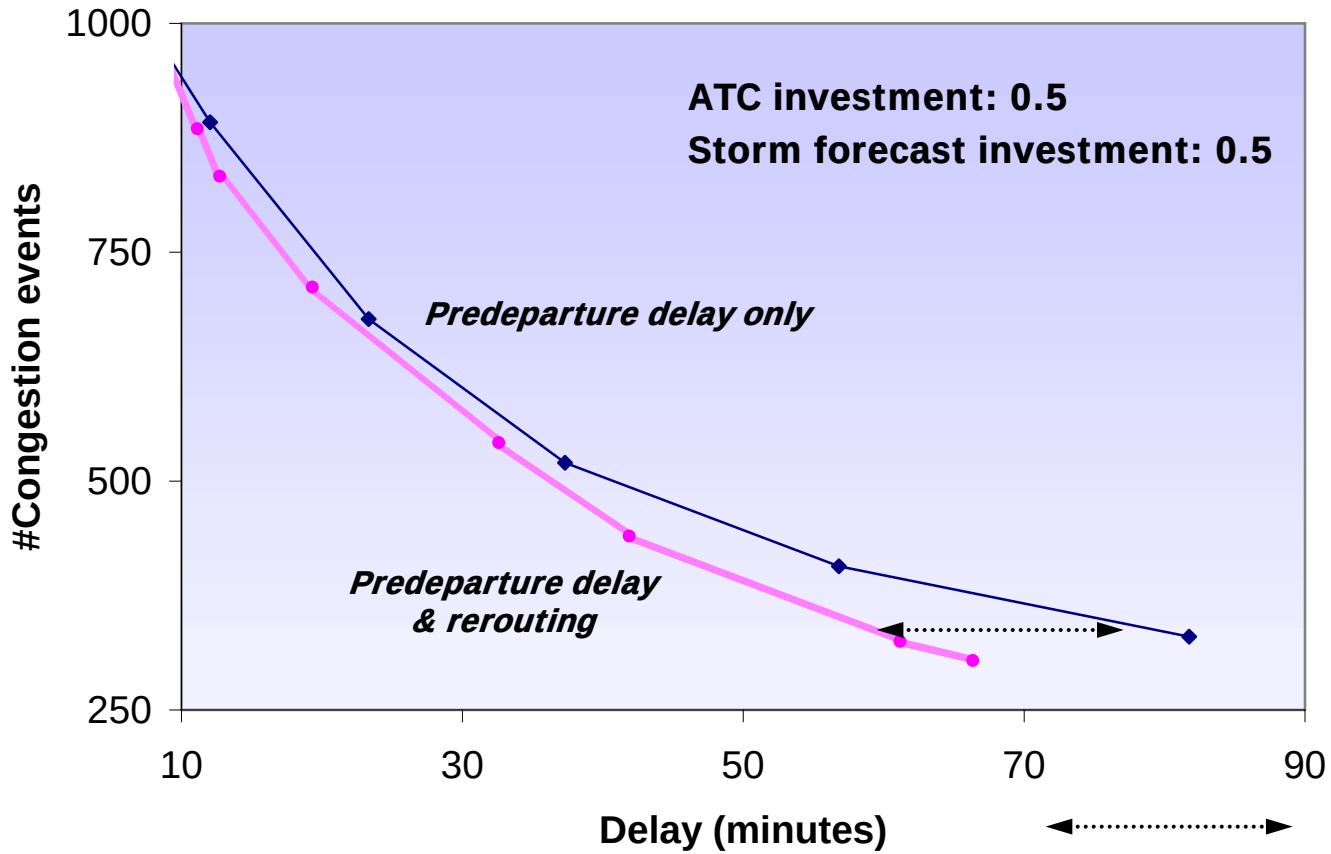
With PreFlight Rerouting



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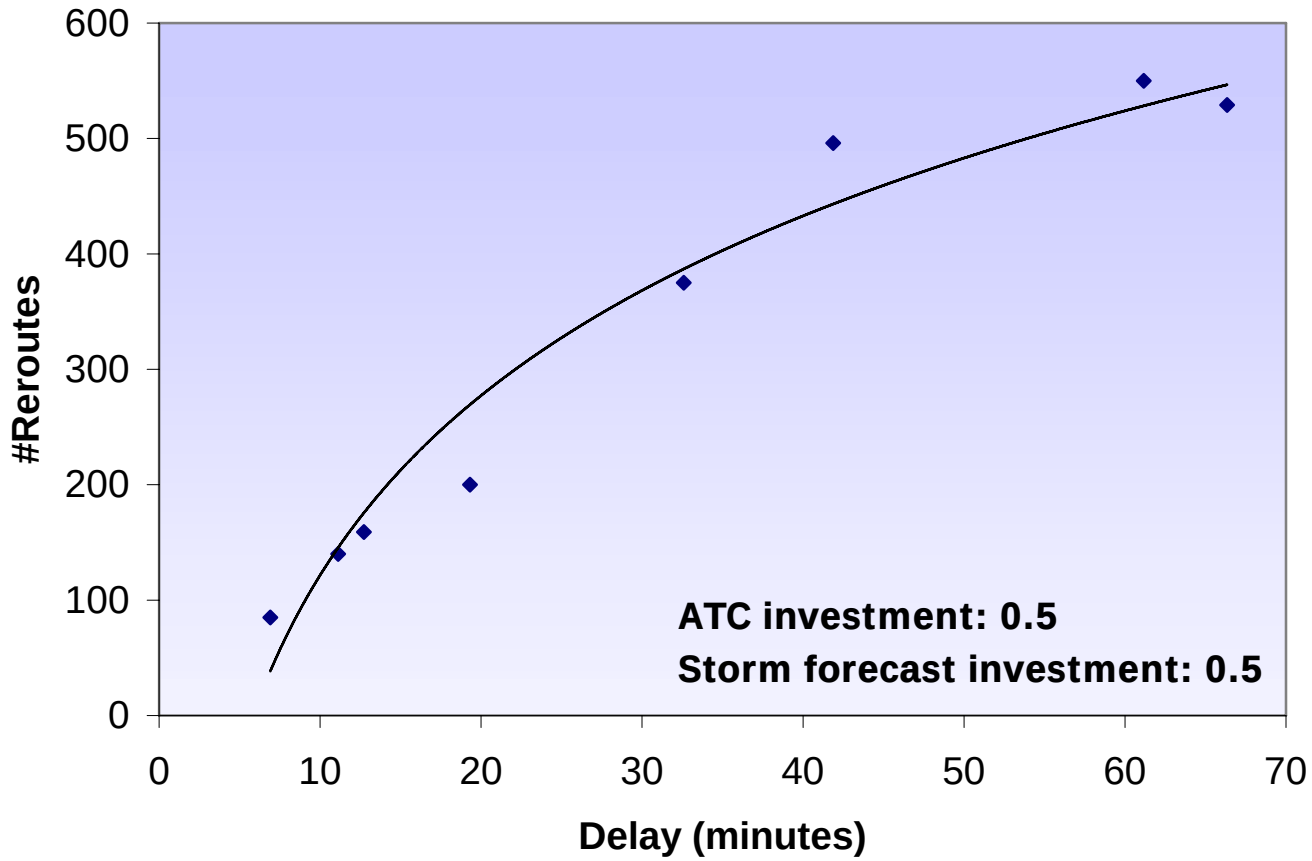
Rerouting Count



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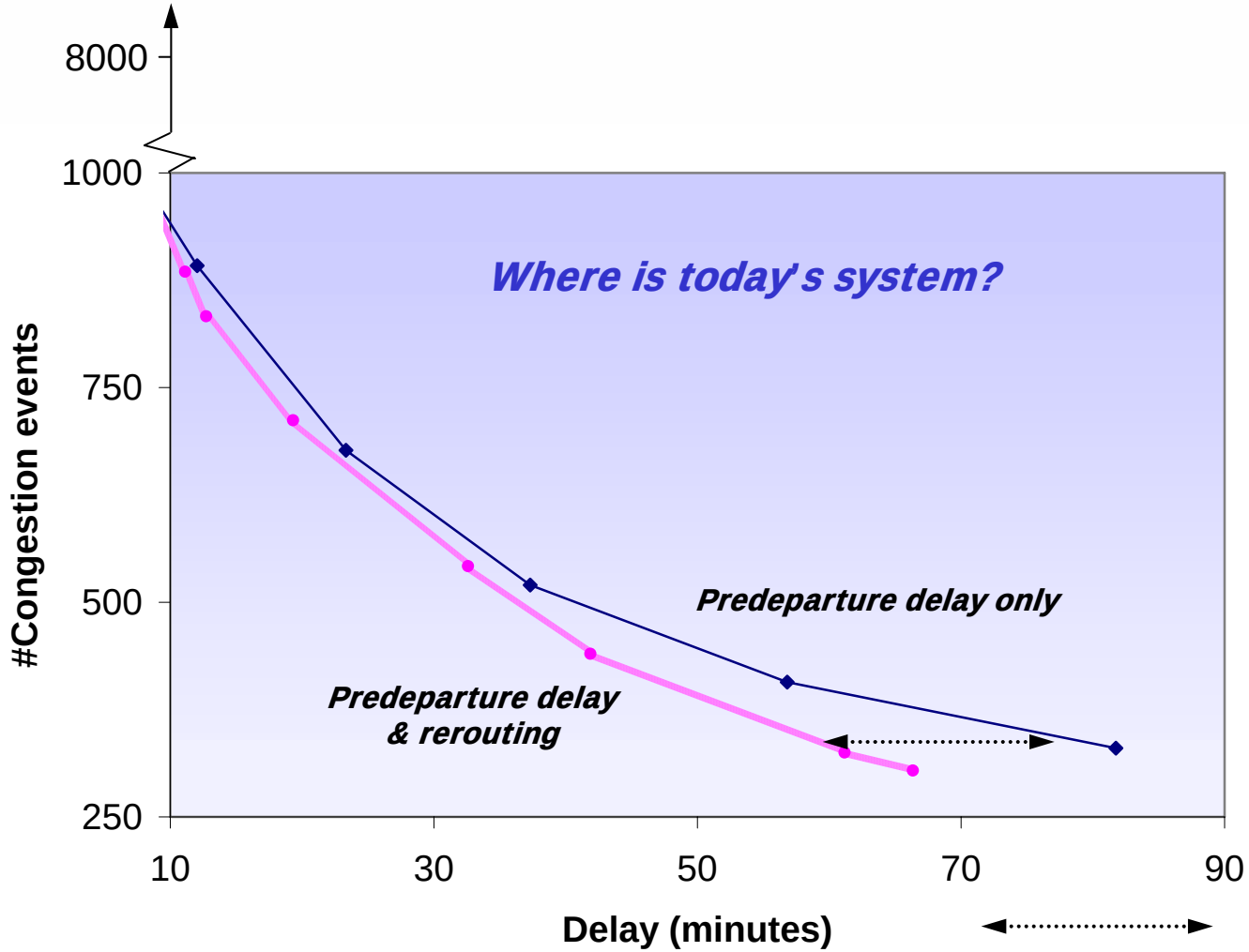
With PreFlight Rerouting



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System Comparisons

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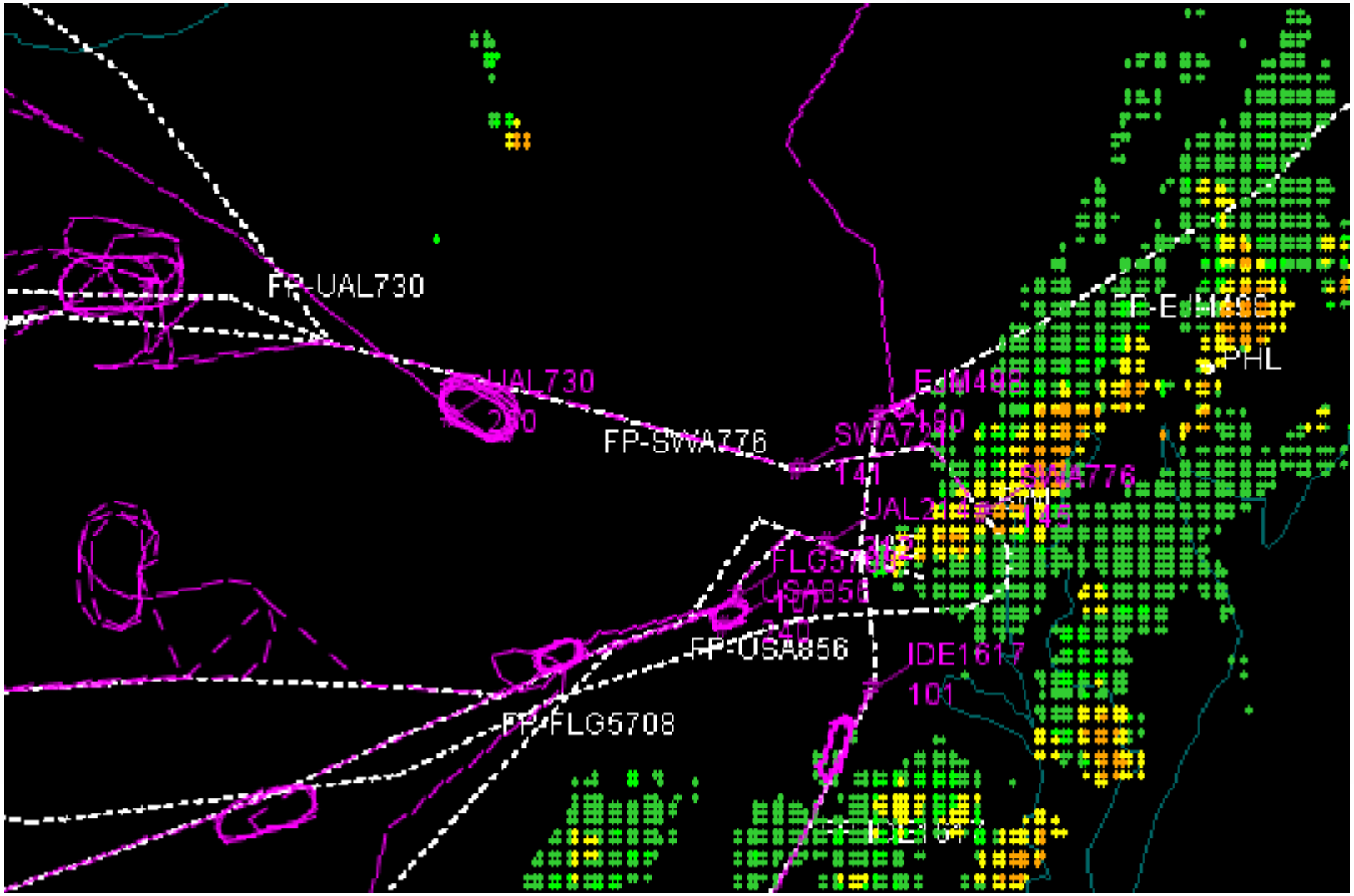
0145 MidAtlantic, 27Jul04



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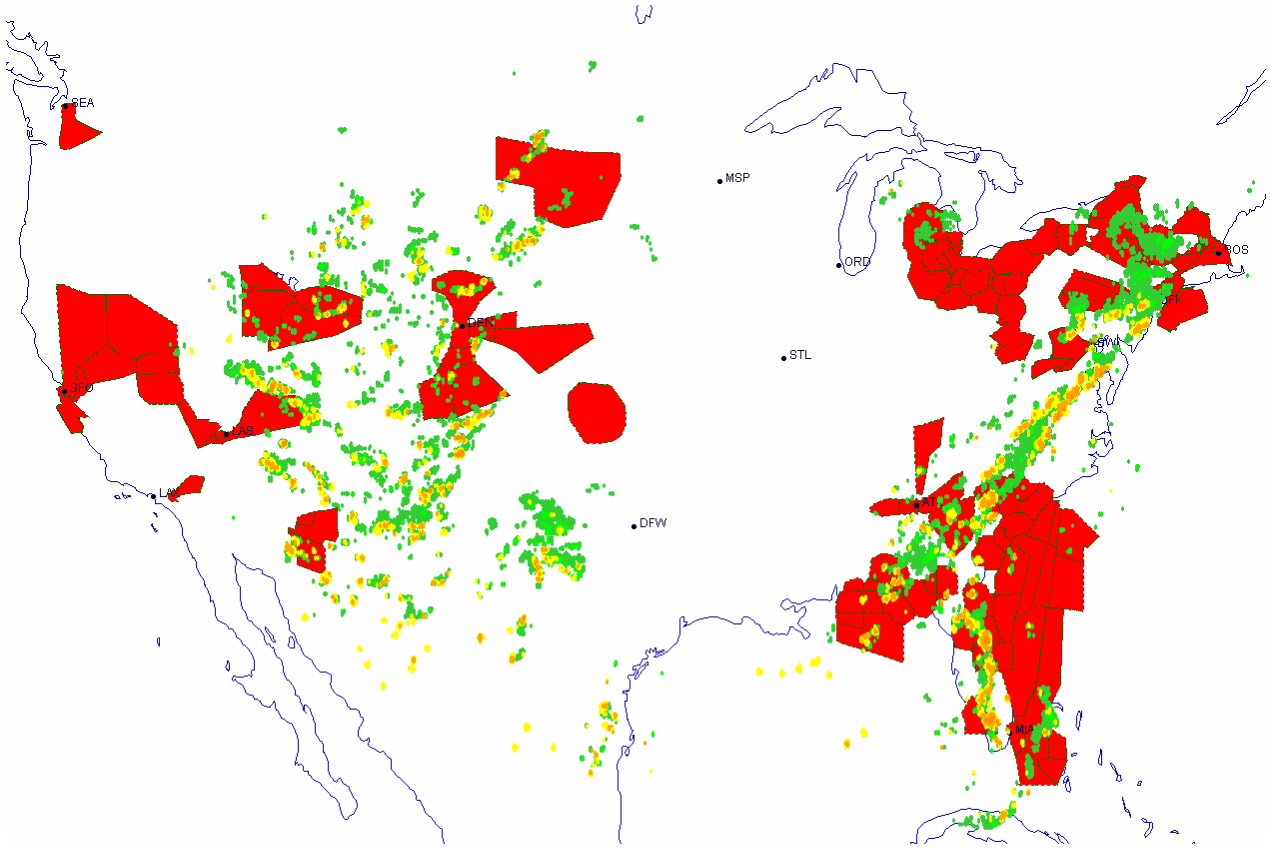
2200 Congestion Map



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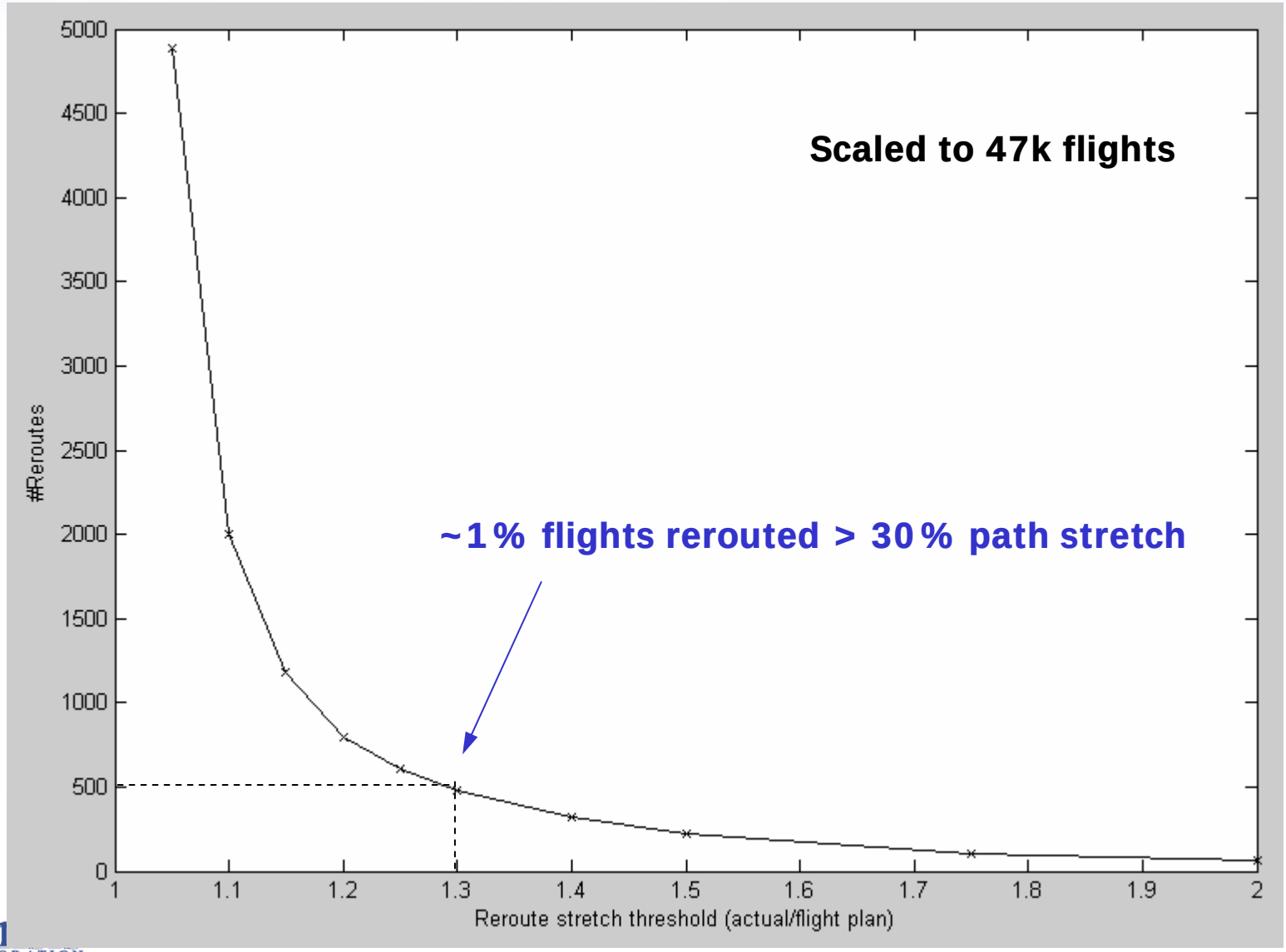
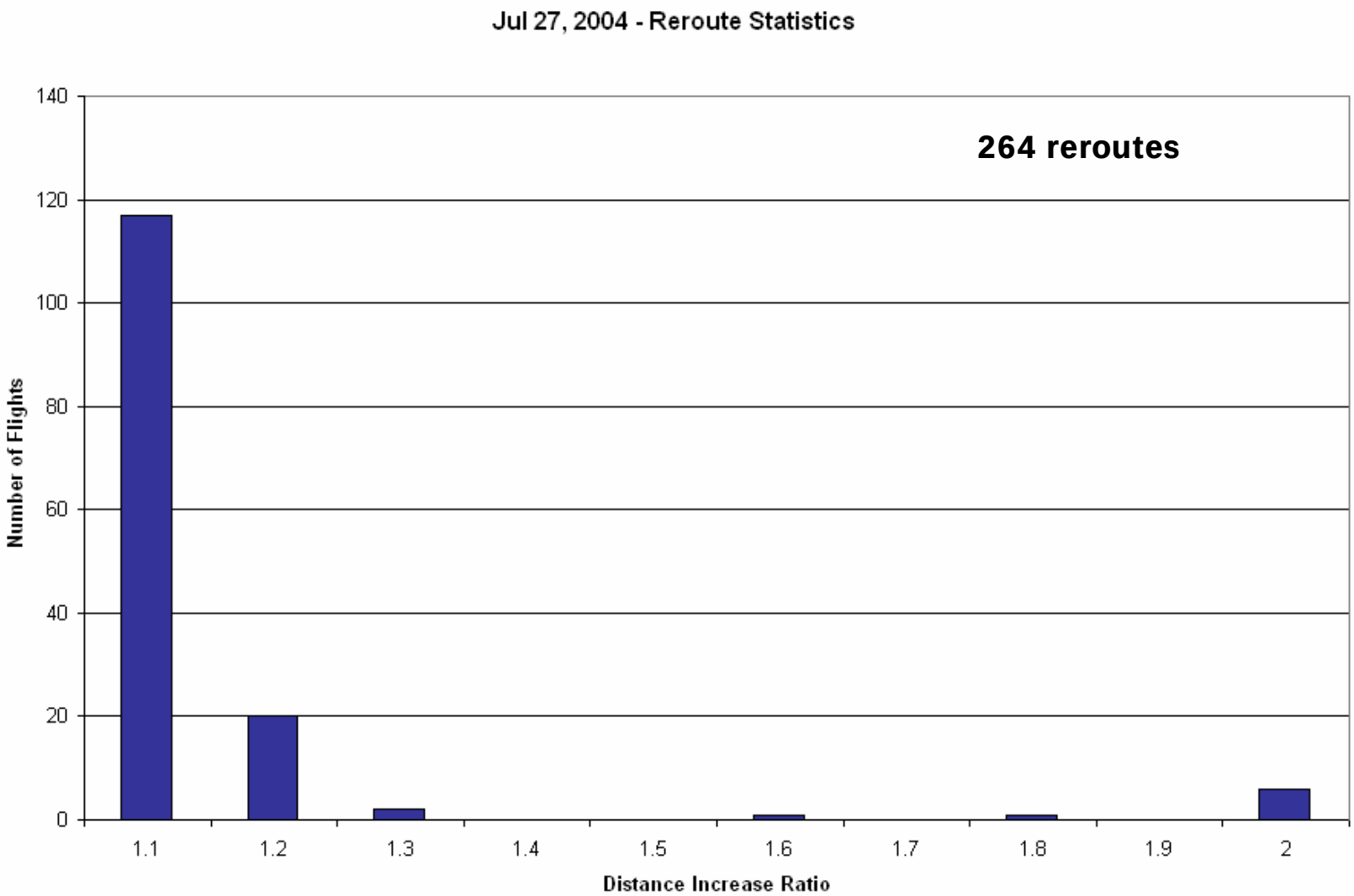
ETMS Reroute Count



Significantly Fewer Reroutes



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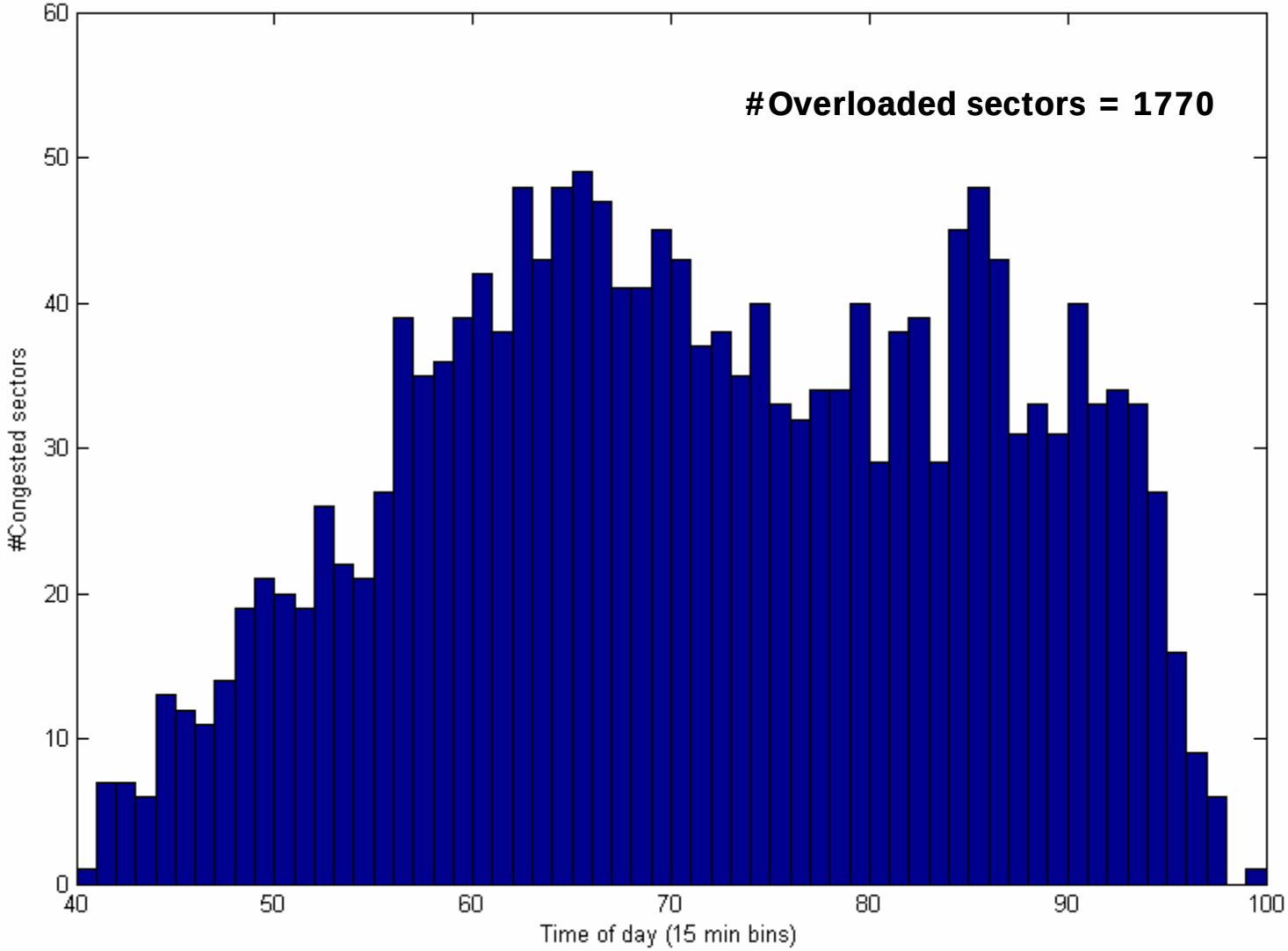
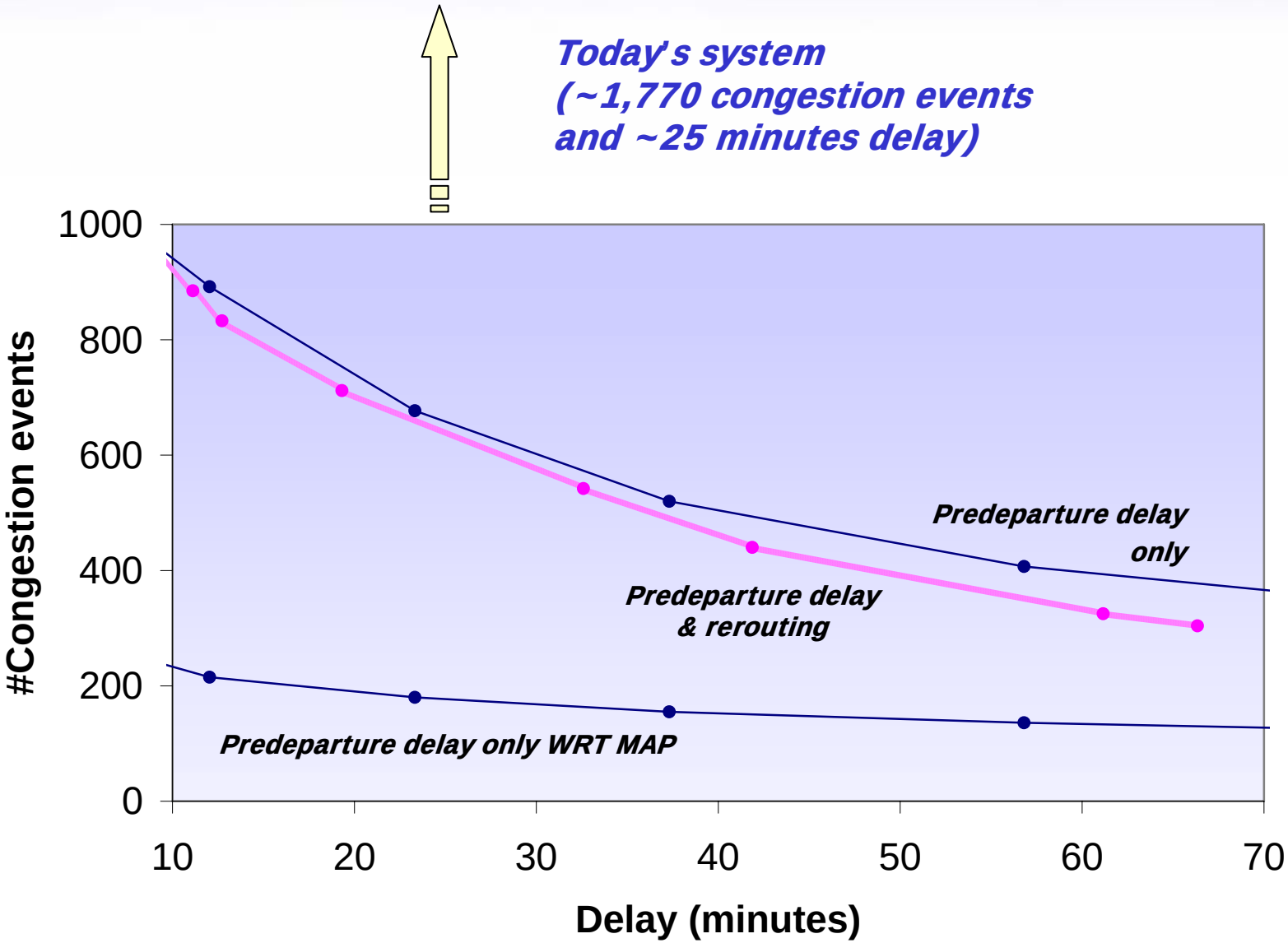
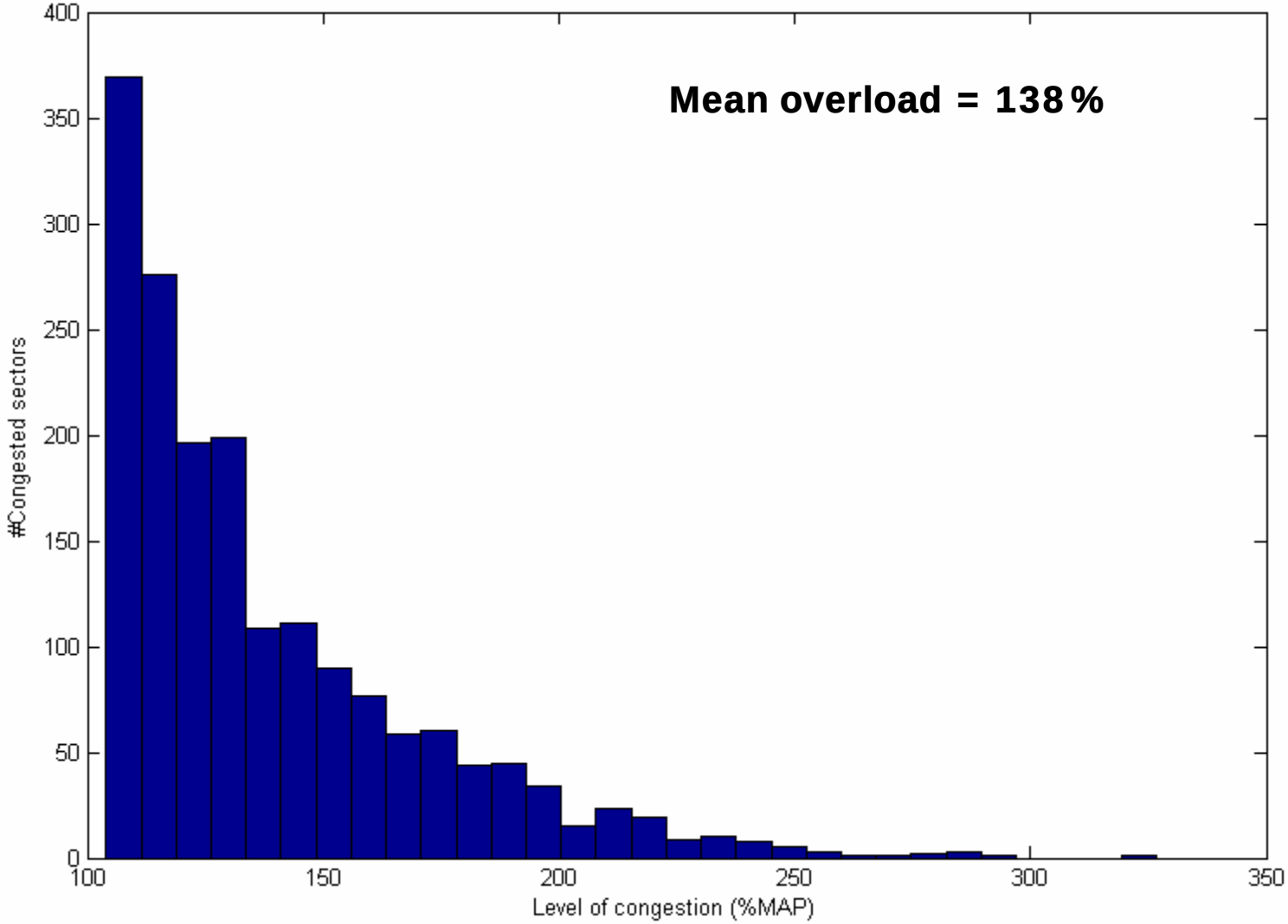
ETMS Congestion Profile



Congestion/Delay Tradeoff Comparison



ETMS Congestion Distribution



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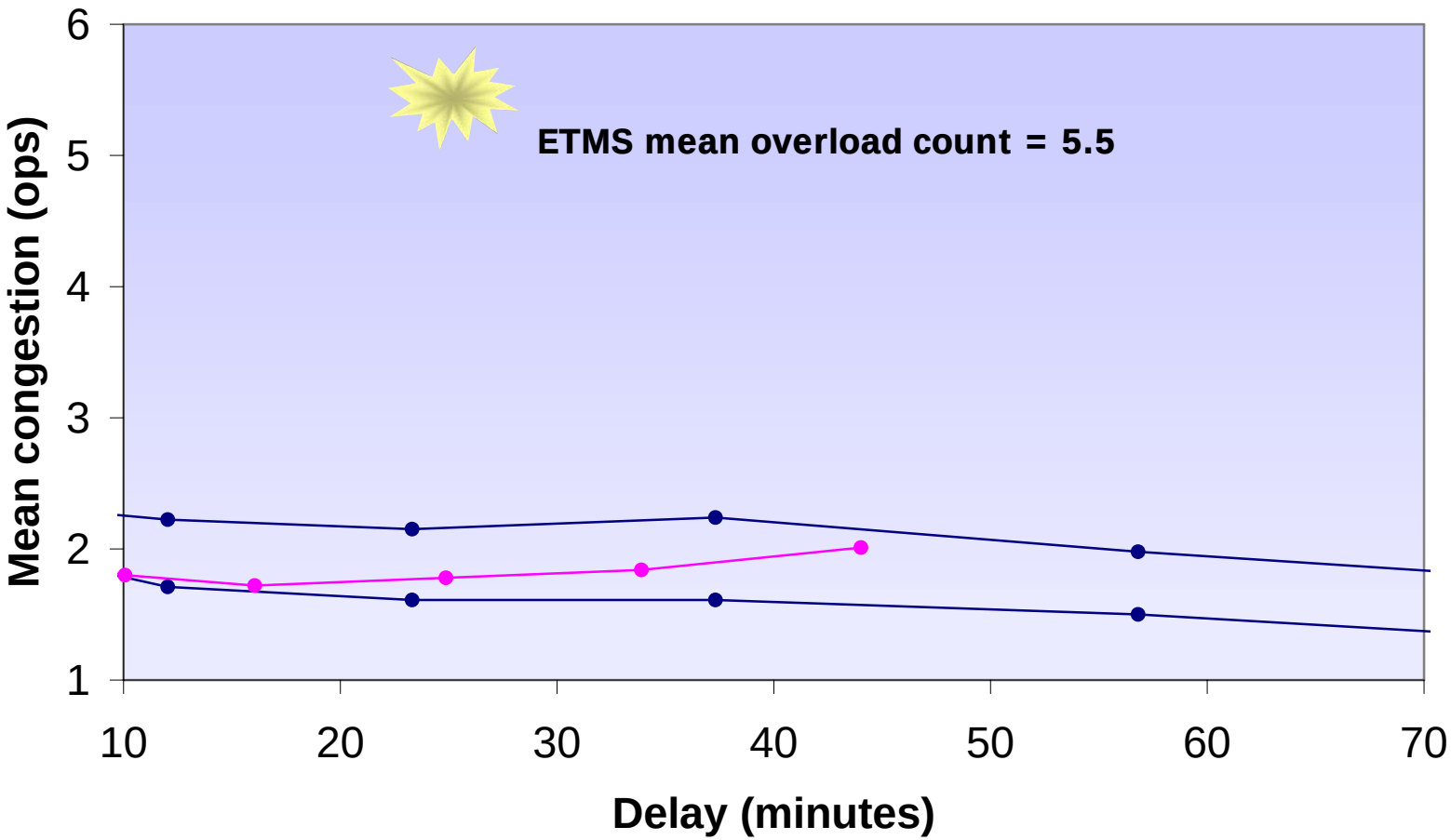
Mean Overload Comparison



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Summary

- Probabilistic TFM evaluation platform
- An ensemble path planning solution
  - Equity solution based on congestion cost
- Good performance in initial testing
  - Fewer reroutes
  - Less delay and congestion
  - Lower levels of congestion
  - More testing needed

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