IV&V Support for VAMS Project

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CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH

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Research Context

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Air Transportation System Models

- Complex, Non-Linear, Adaptive, Stochastic Network
- No Adequate Model Currently Exists (may never be formulated)
- Event Based Simulations are an Attempt to Gain a Better Understanding of the Non-Linear Feedback Loops in this System
- Network Managers need to Understand the Optimum Control Inputs to Maximize Network Throughput and Ensure Network Stability

GMU Emphasis:

- Better Characterization of the Network Stochastic Behavior for Simulation Validation
  - Cancellations vs. Delays (Hub A/P and Airline Specific)
  - IMC vs. VMC
- Use of Simulations for Optimum Network Design
- Use of Simulations for Congestion Management Network Control

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Verification & Validation Support

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Main tasks

1. **Bayesian network approach**
   - Develop Bayesian networks to model the complex, highly nonlinear, stochastic behaviors for NAS
   - Capture the complex relationship between variables in NAS, e.g.
     - Show how the delays are propagated to different airports under different weather conditions
     - Show how cancellation is impacted by other variables
2. **Enroute Workload Estimation & Center Redesign**
   - Air traffic controller workload estimation
   - Airspace complexity quantification
   - Center Redesign (Define Optimum Center Boundaries)

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Additional GMU Research Tasks

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Highly Useful for VAMS Project

1. **Congestion Management (Runway Time Slot Auctions)**
   - **Reduce flight delay, while Increasing Network Enplanement Throughput**
   - **Has potential to improve operational safety level**
   - **Now Part of JPDO Plan**
2. **Airport Safety Modeling and Analysis**
3. **Efficient Stochastic Simulation & Optimal Screening Method for Best Alternative Selection**
4. **FAA Funded Related Effort of Evaluating the FAA NAS Strategy Simulator Feedback Loops**

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Task 1: V&V using Bayesian Network

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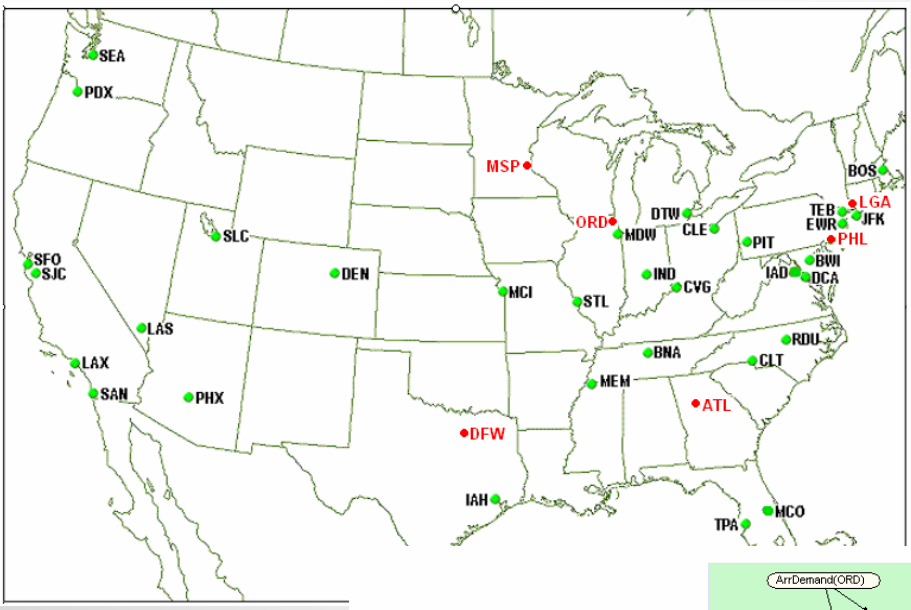

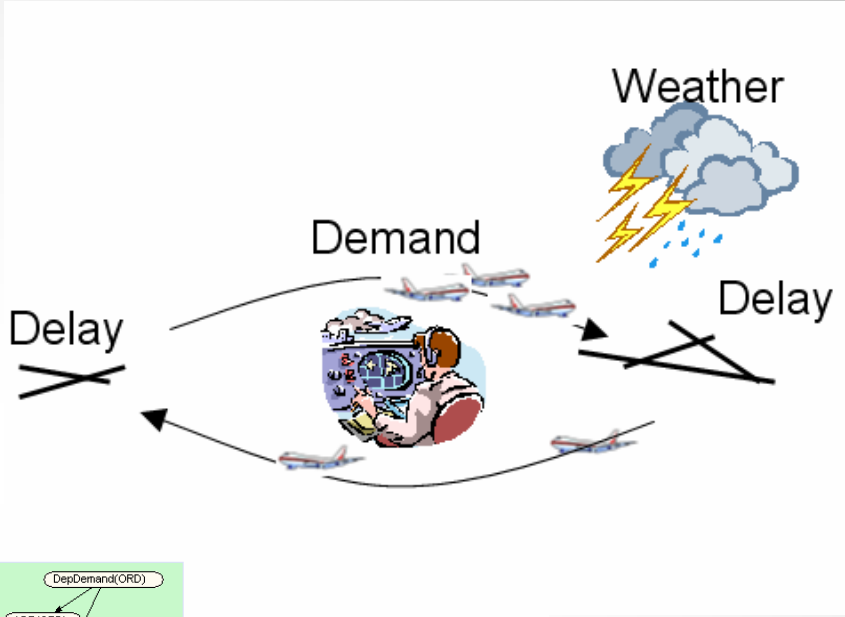

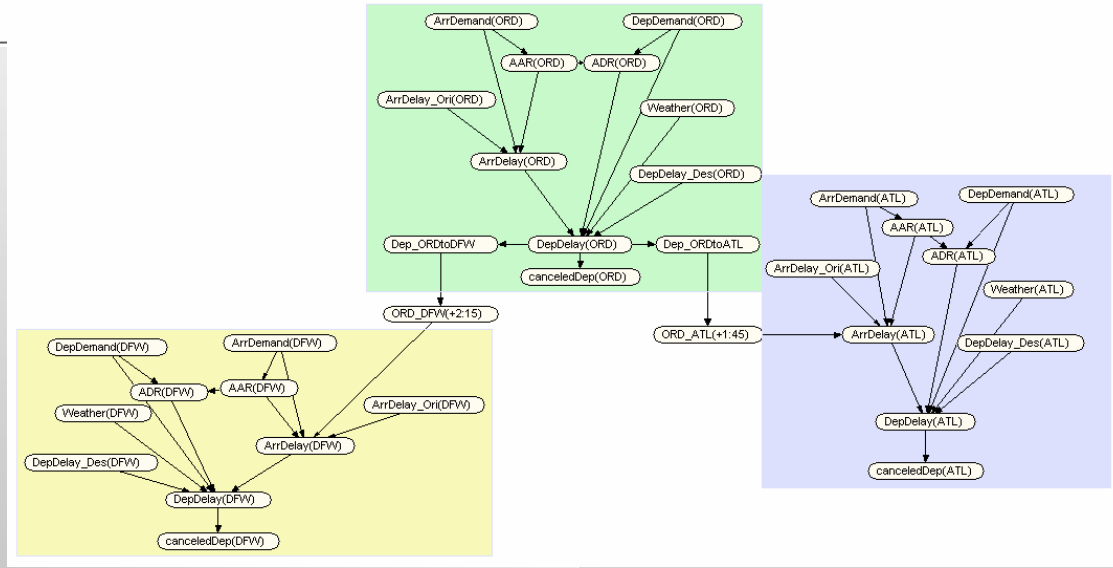

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Bayesian Network (BN) & Netica Notation

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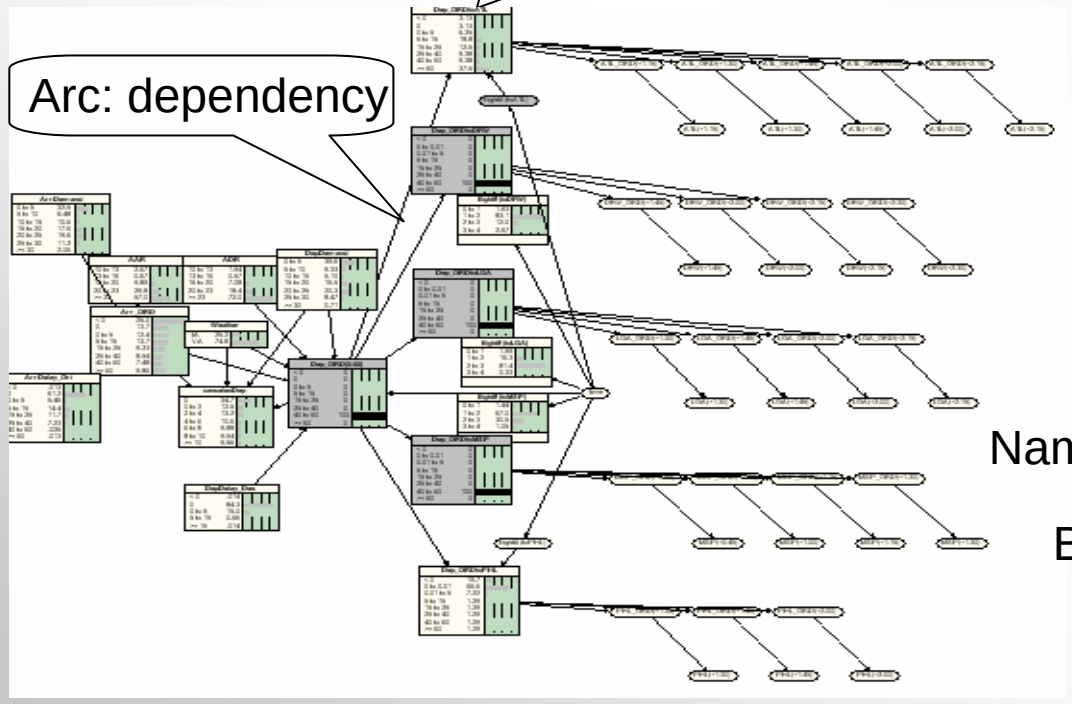
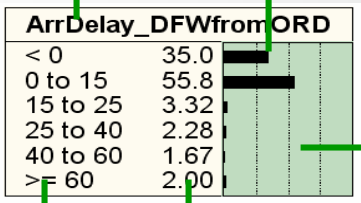
Node: a variable of interest

Arc: dependency



Node's name/ title

Bar: belief amount

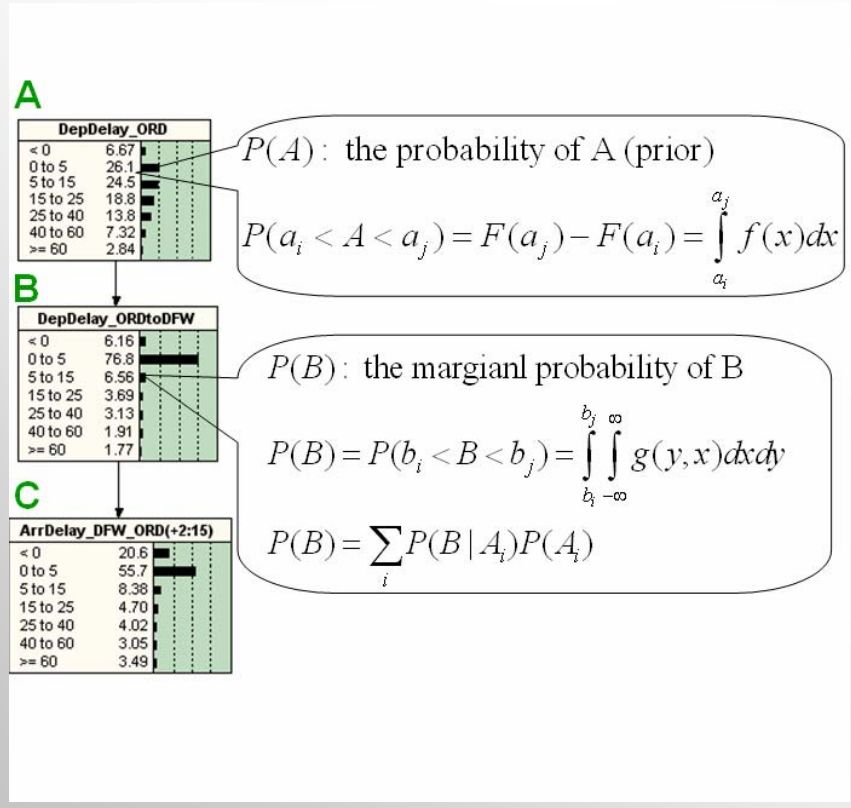


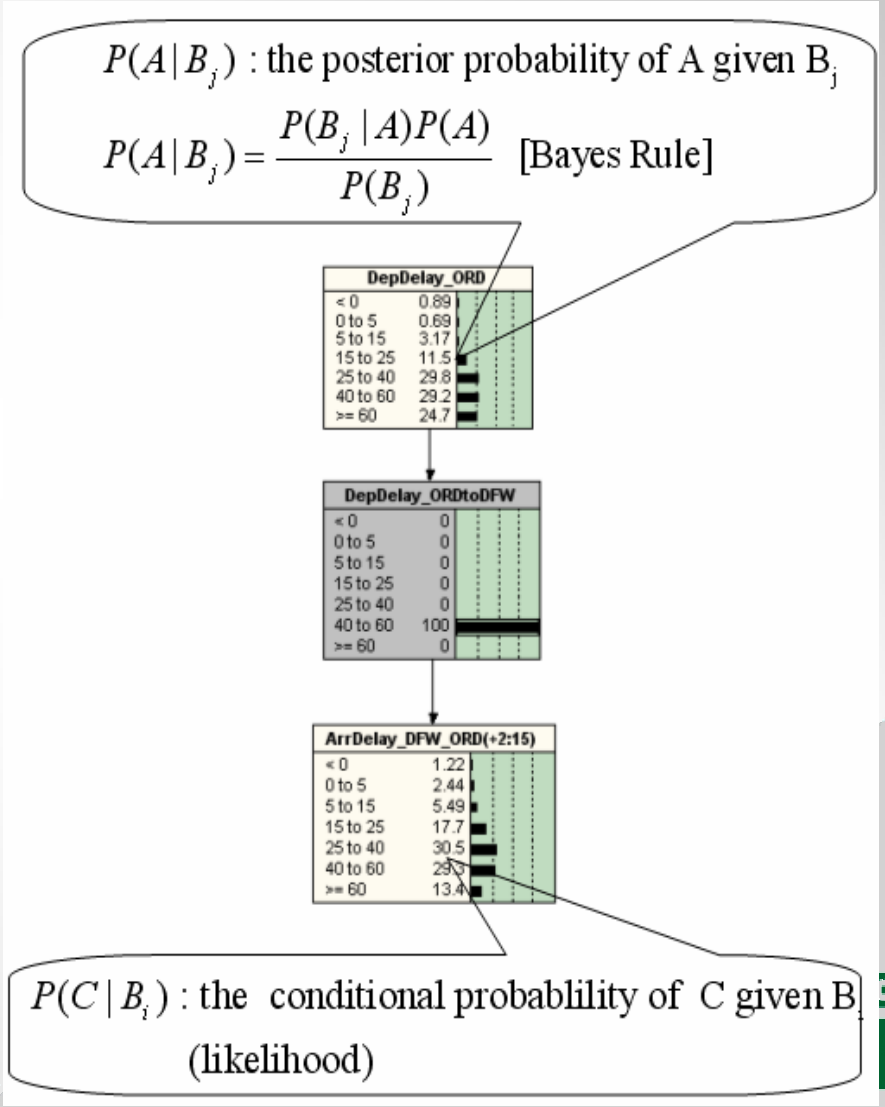
.25
.5
.75

Name/ range for each state

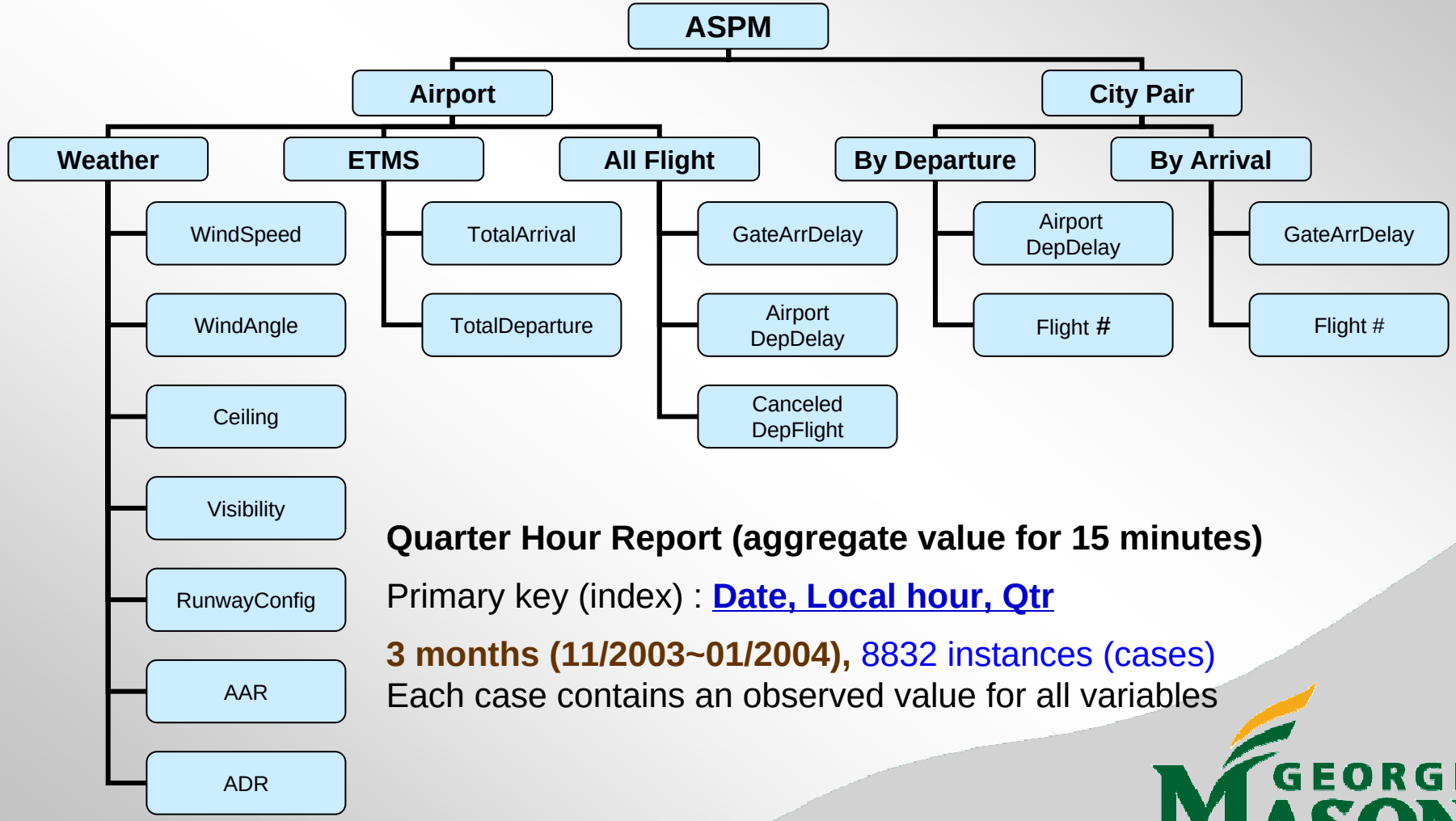
Belief (probability) as a percentage

Bayesian Inference





Database for Analysis



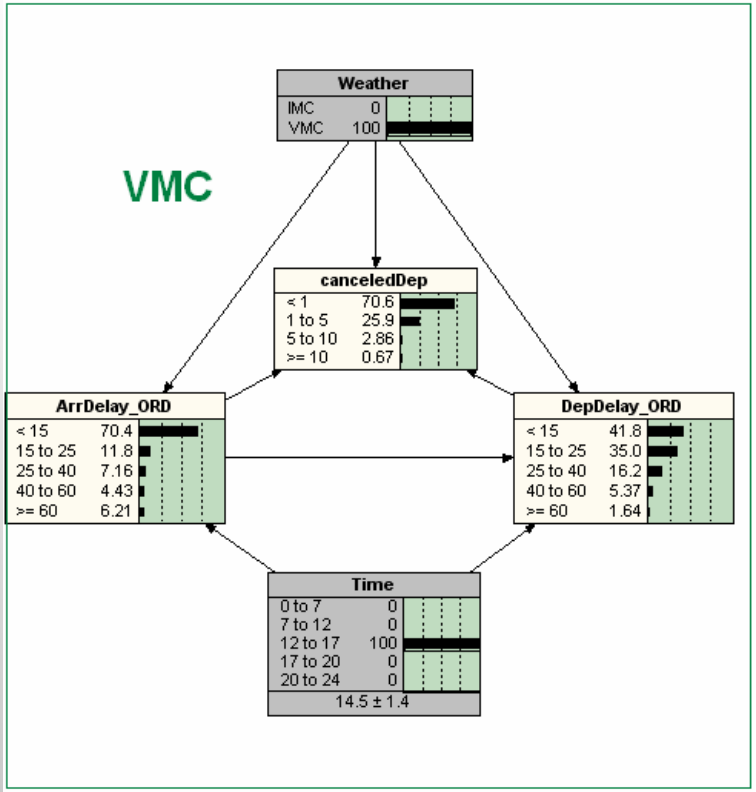
Quarter Hour Report (aggregate value for 15 minutes)

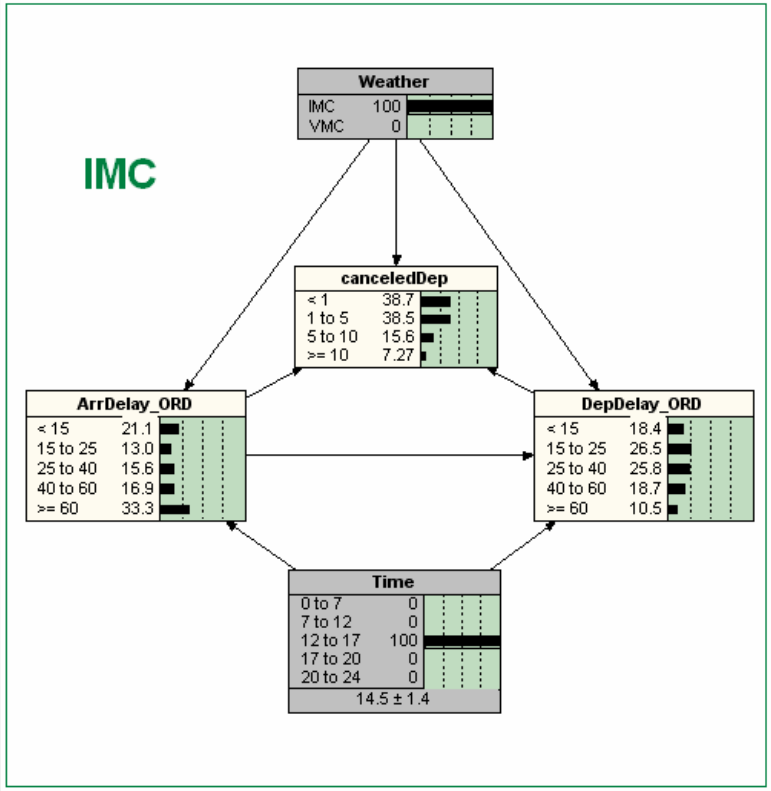
Primary key (index) : **Date, Local hour, Qtr**

3 months (11/2003~01/2004), 8832 instances (cases)

Each case contains an observed value for all variables

Weather Effect: ORD





Delay Propagation from ORD

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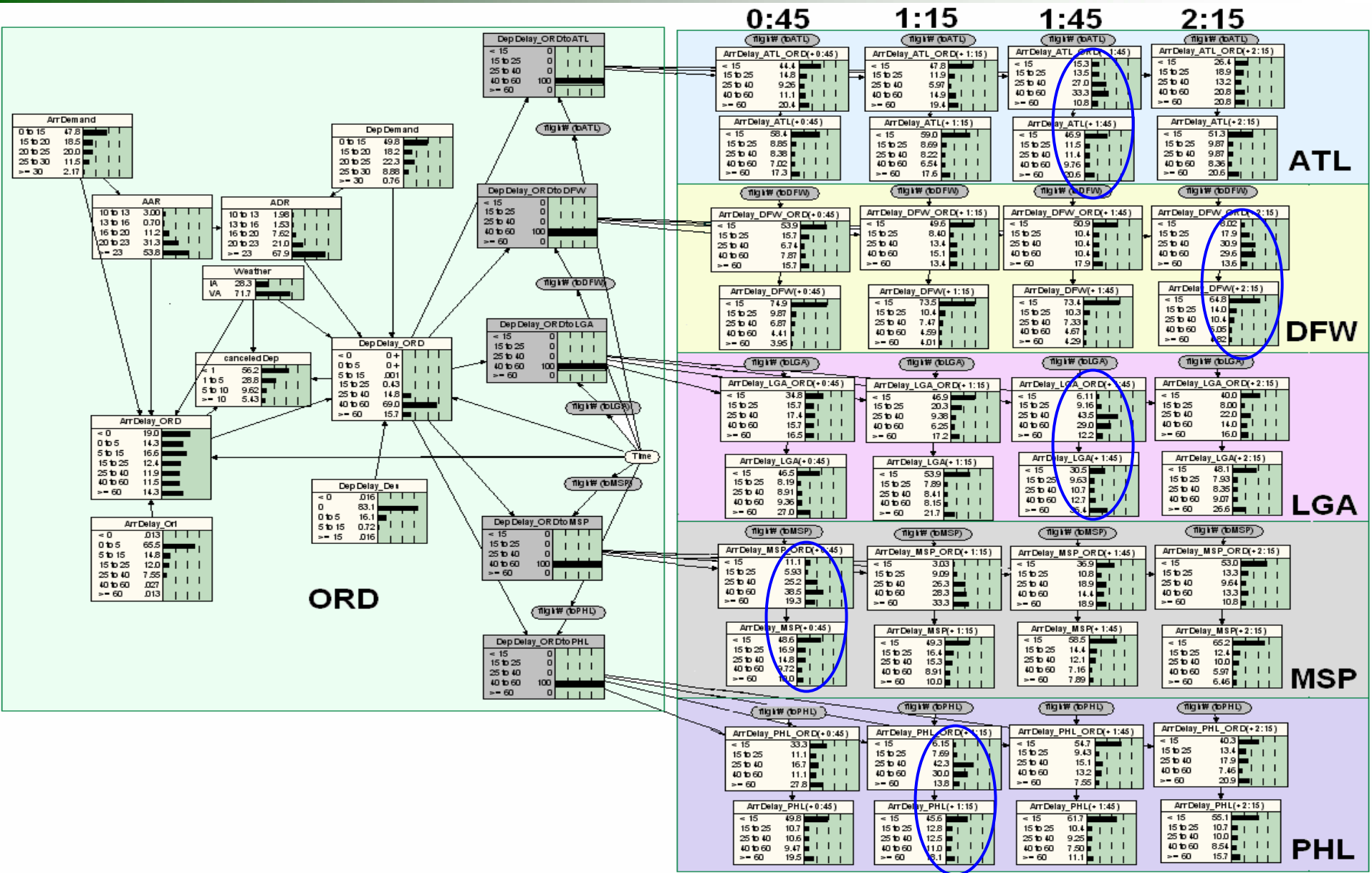

Delay Propagation Into ATL

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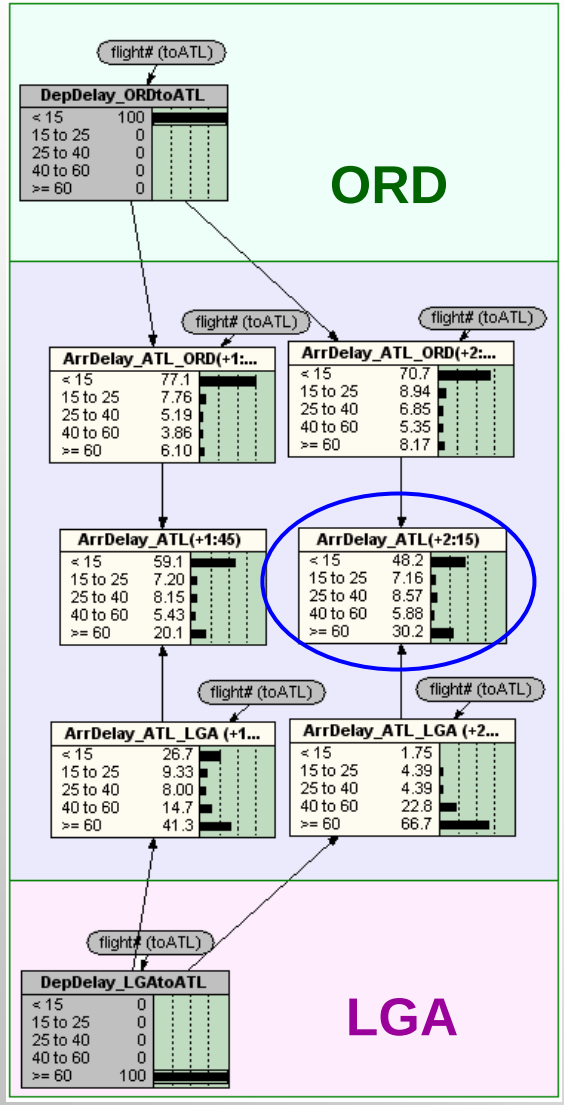
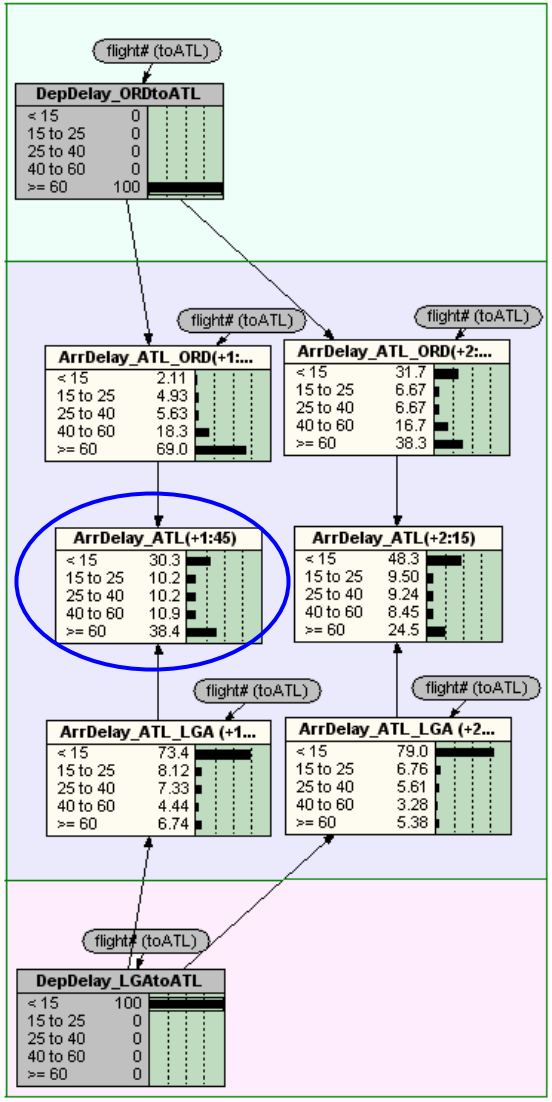
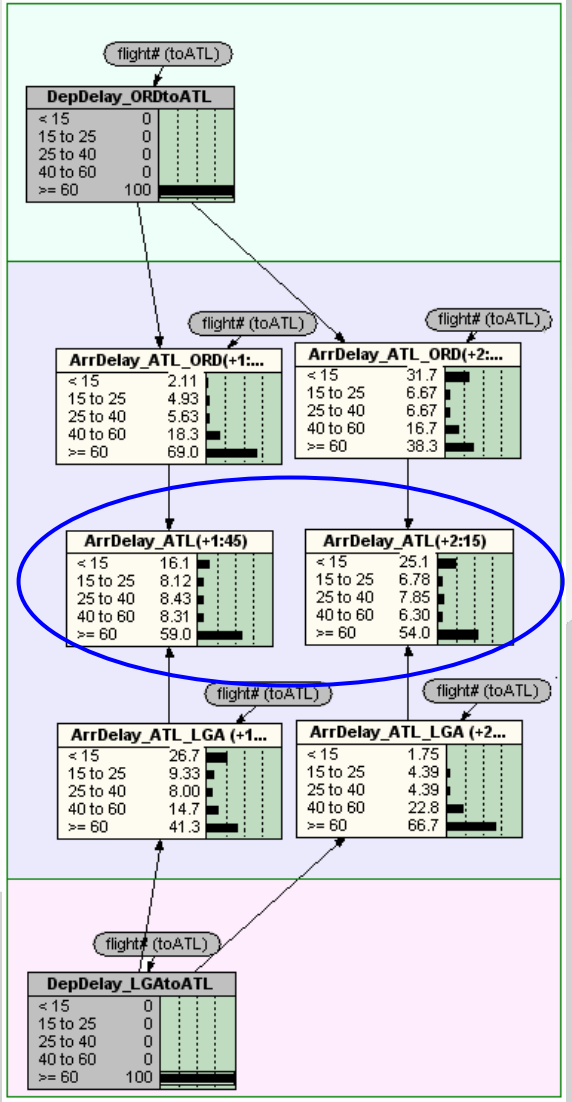
Scenario 1 - LGA Delay



Scenario 2 - ORD Delay



Scenario 3 - Both Delay



Flight Cancellation Model

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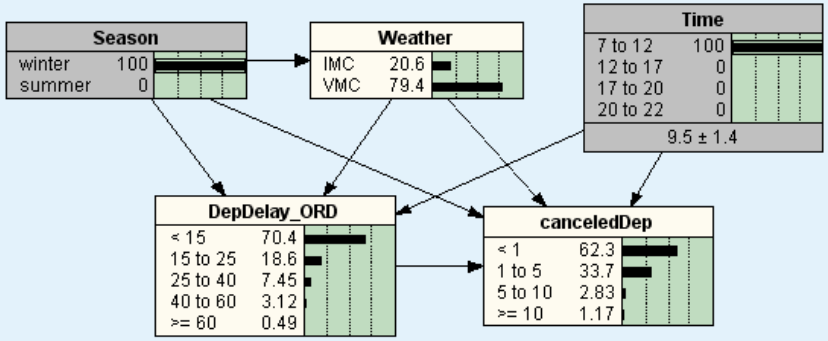
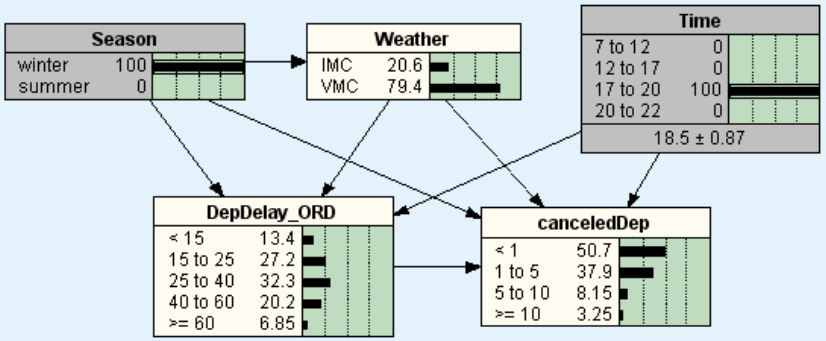
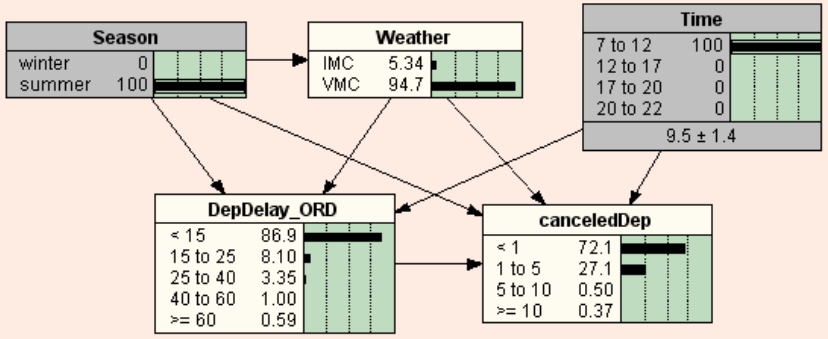
Cancellation is critical for accurate delay estimation



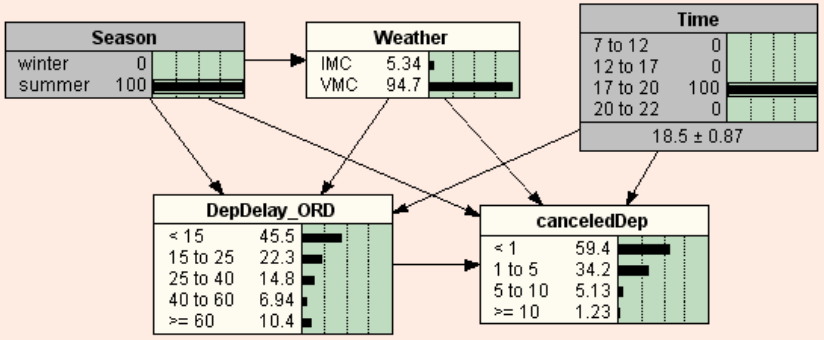
Winter Morning



Winter Evening

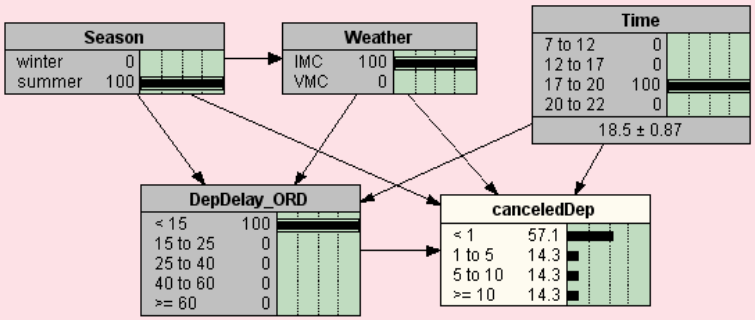


Summer Morning

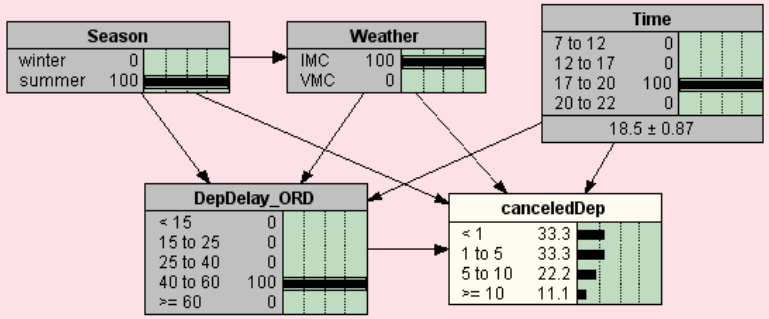


Summer Evening

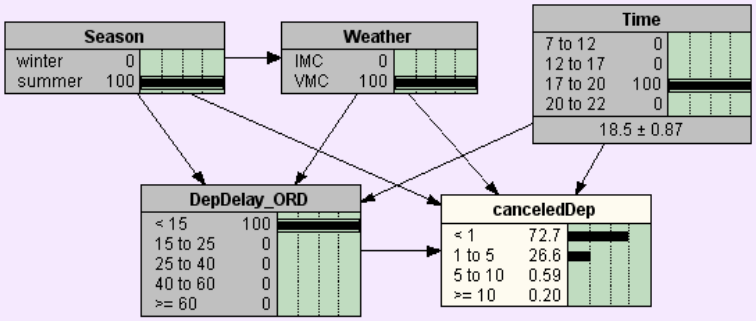
Flight Cancellation Model (Cont'd)



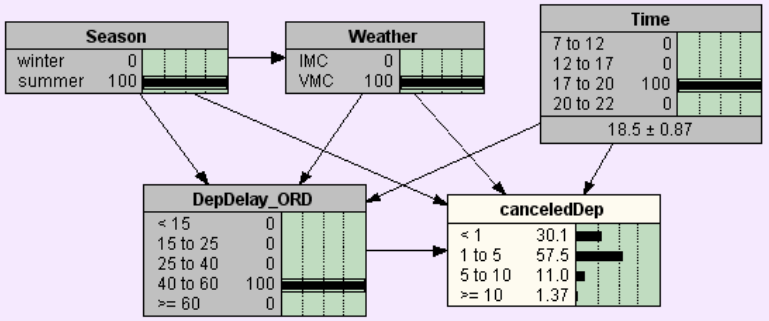
IMC, DepDelay<15mins



IMC, 40<DepDelay<=60mins



VMC, DepDelay<15mins



VMC, 40<DepDelay<=60mins

BN Conclusions to Date

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- **We have shown**
  - **How delay and cancellation is impacted by weather**
  - **How delay is propagated from the network into ATL**
  - **How delay is propagated from ORD to the network**
  - **A potential flight cancellation model**
- **Develop a Bayesian Network**
  - **Modeling the complex, highly nonlinear, stochastic behaviors for NAS**
  - **Capturing complex relationship between variables in NAS**
  - **Leading to development of a flight cancellation module for simulators such as ACES**

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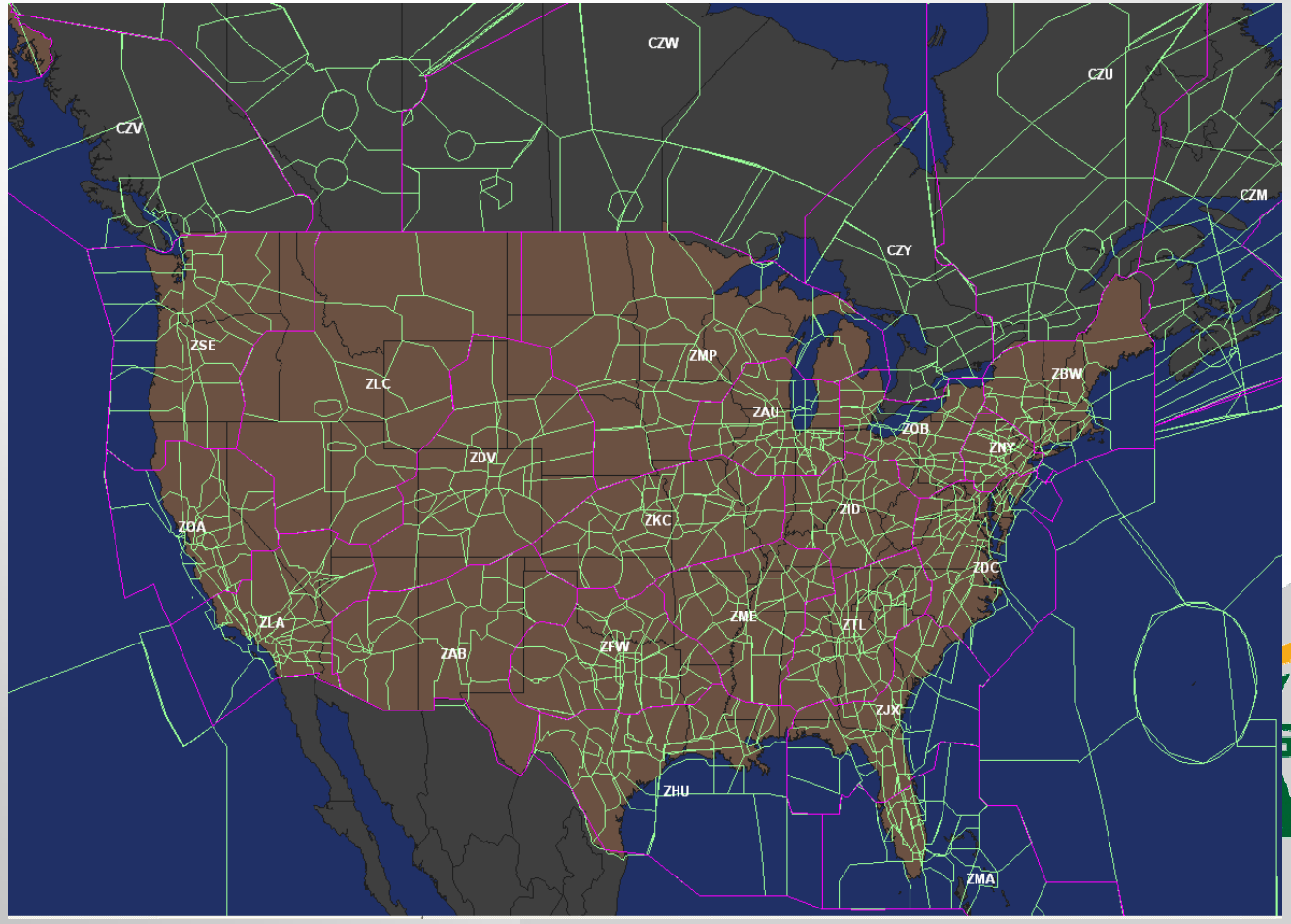
Task 2: Validation via Enroute Workload Estimation & Center Redesign: Arash Yousefi, PhD Dissertation 2005



CENTER FOR

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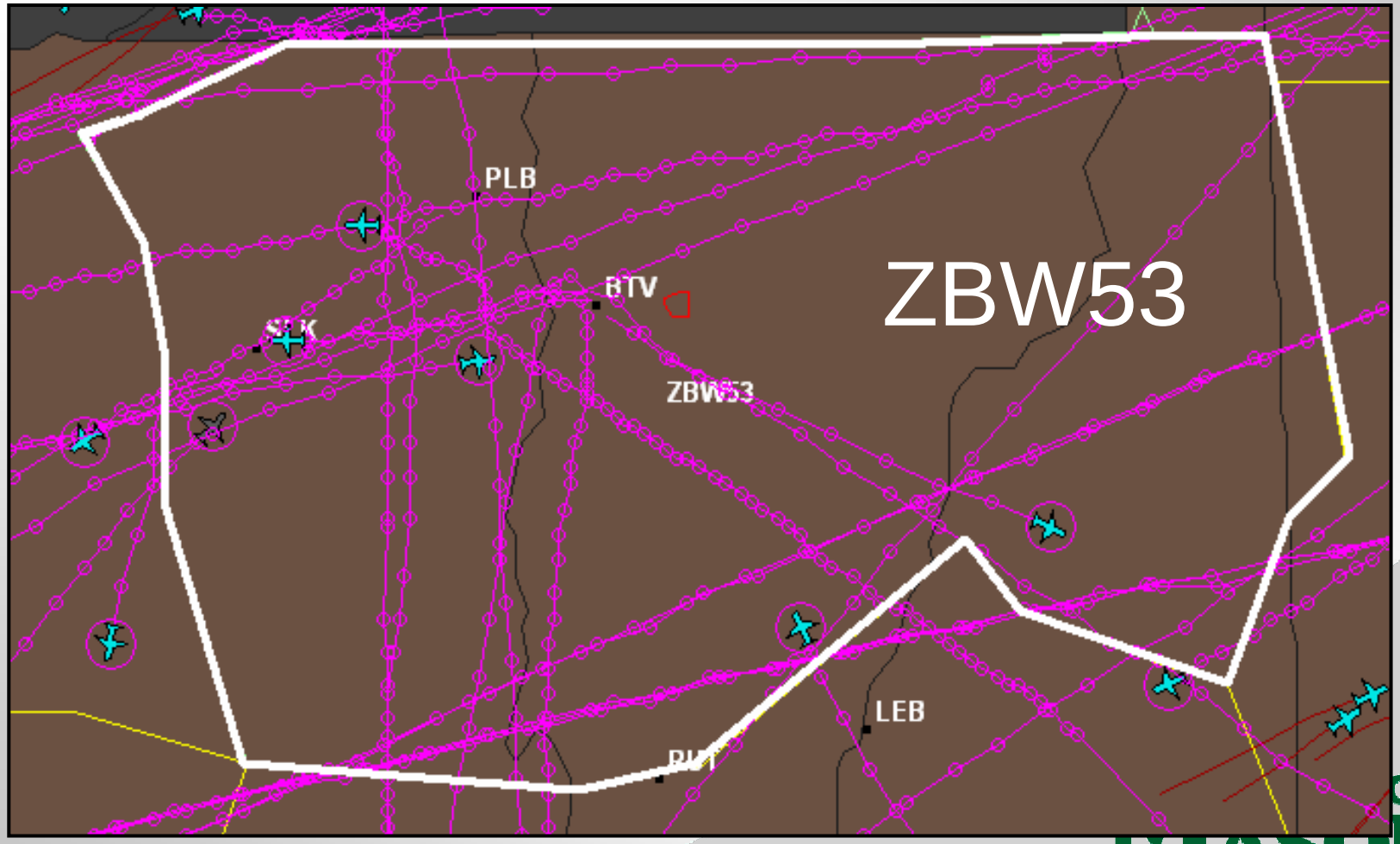
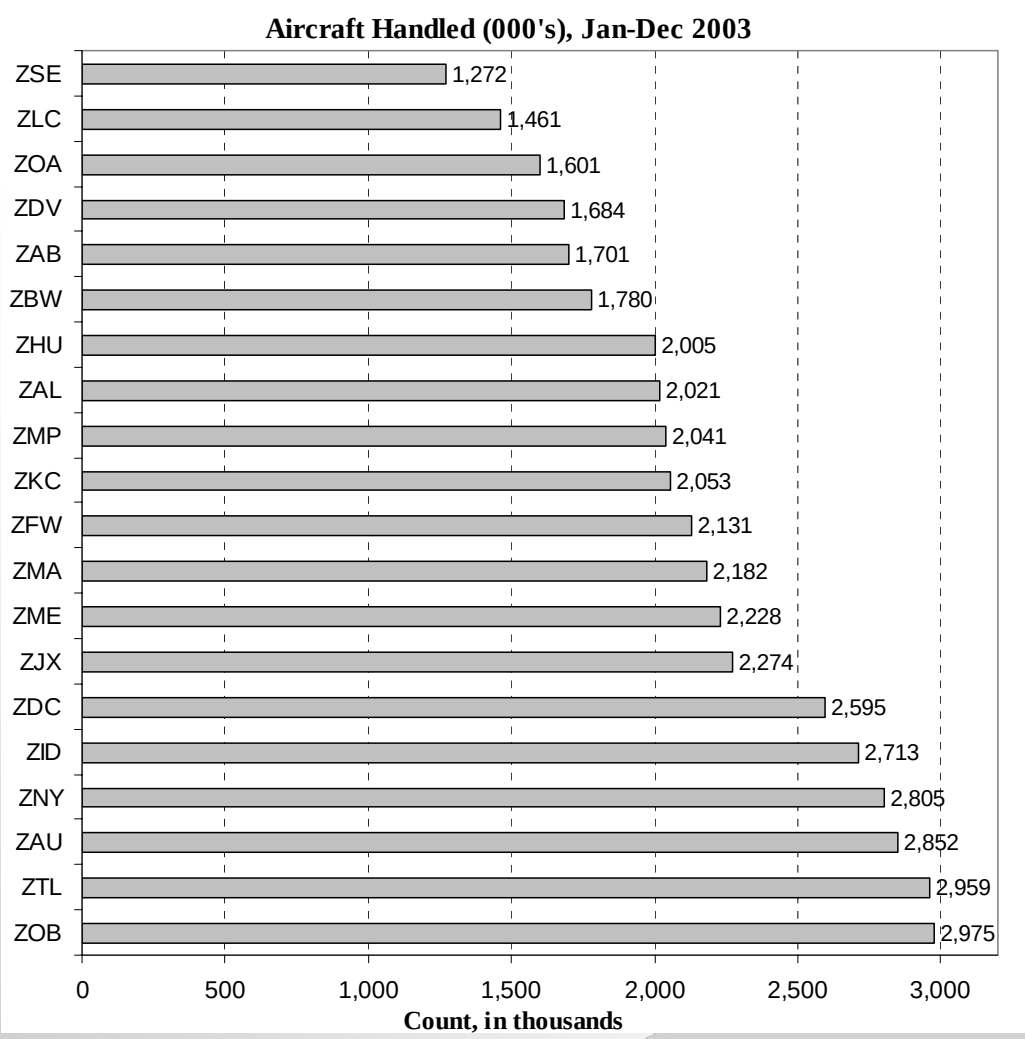
Current Airspace Design is Far from Optimum



FAA ARTCC Overhead is Not Efficiently Allocated



Source: FAA Factbook, March 2004. URL: *http://www.atctraining.faa.gov/factbook*

ATC Workload Modeling

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ATC Workload is Modeled as a Combination of 4 Simulation Variables:

1. **Horizontal Movement Workload (*WLHM*)**
   - **determined by sector density & average flight time**
2. **Conflict Detection and Resolution Workload (*WLCDR*)**
   - **based on the conflict type & severity**
3. **Coordination Workload (*WLC*)**
   - **type of coordination action including: voice call, clearance issue, inter-facility transfer, silent transfer, intra-facility transfer**
4. **Altitude-Change Workload (*WLAC*)**
   - **determined by the type of altitude clearance request for level-off, commence-climb and commence-descent**

$$TotalWL = \sum(WLHM, WLCDR, WLC, WLAC)$$

More details:

Yousefi, A., Donohue, G. L., and Qureshi, M. Q., "Investigation of En route Metrics for Model Validation and Airspace Design", *Proceeding of the 5th USA/Europe Air Traffic Management R&D Conference*, Budapest, Hungary, June 2003.

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Uniform Airspace Partitioning is Key to Center/Sector Optimization Success

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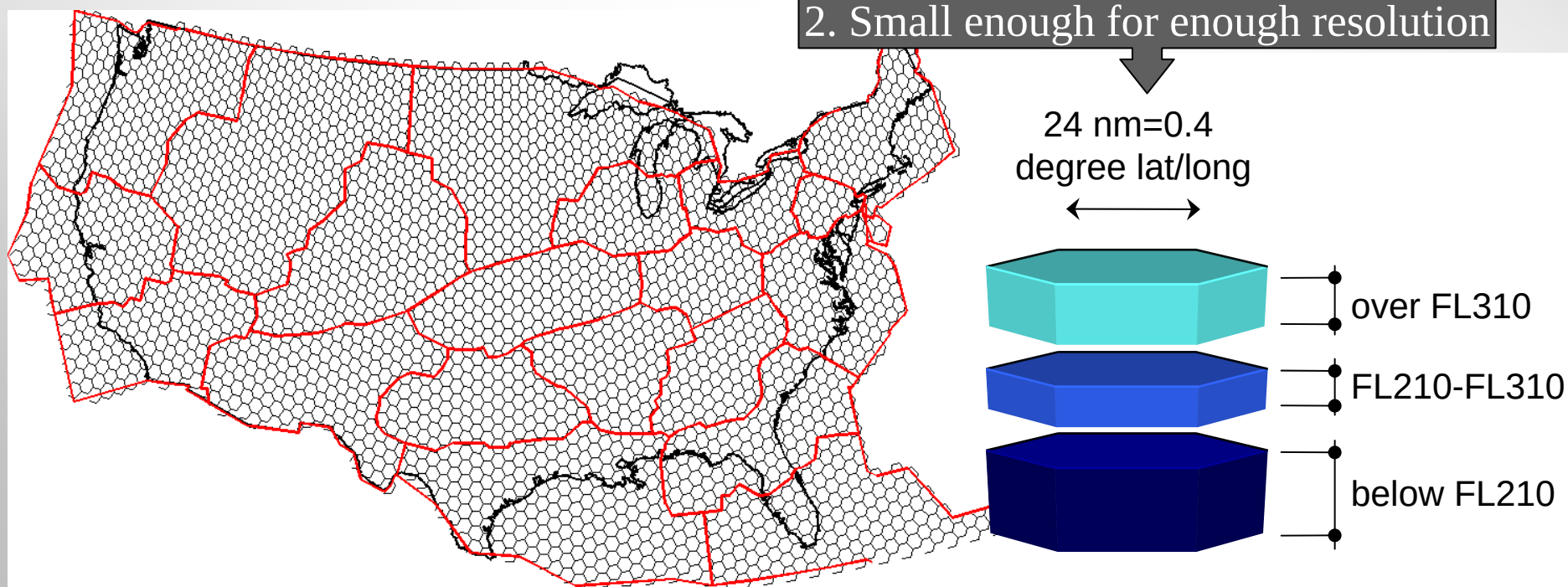
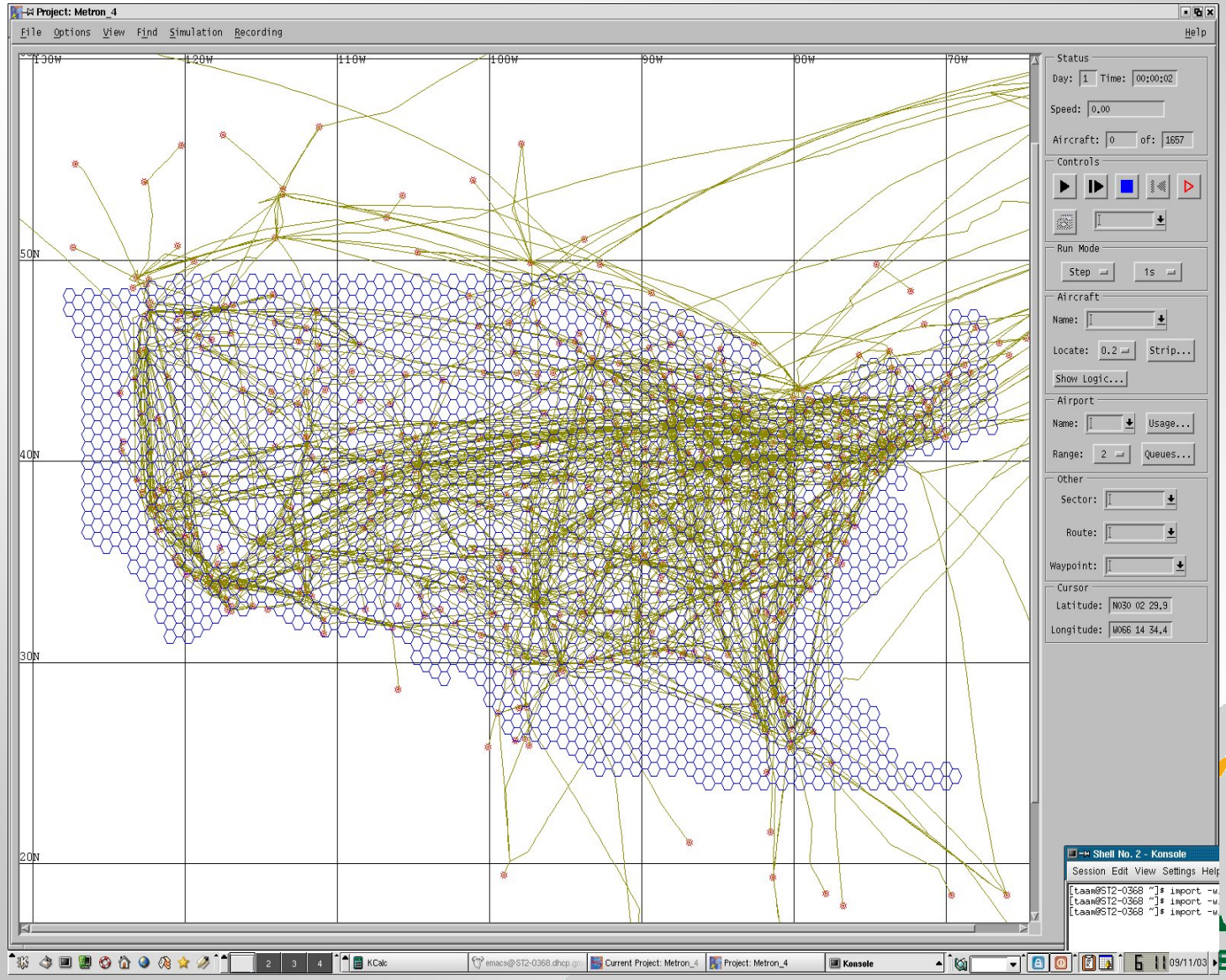
- **The airspace of 20 CONUS ARTCCs is divided to three altitude layers with 2,566 cells.**
- **Existing Center and Sector boundaries MUST be Eliminated**
- **Hex-Cells are airspace elements and it is possible to compute complexity and workload metrics for each cell based on historic flight data and simulation**

1. Large enough to capture conflicts
2. Small enough for enough resolution



TAAM Simulation used in Absence of ACES Model



Airspace Complexity Visualization Used for Consistency Check

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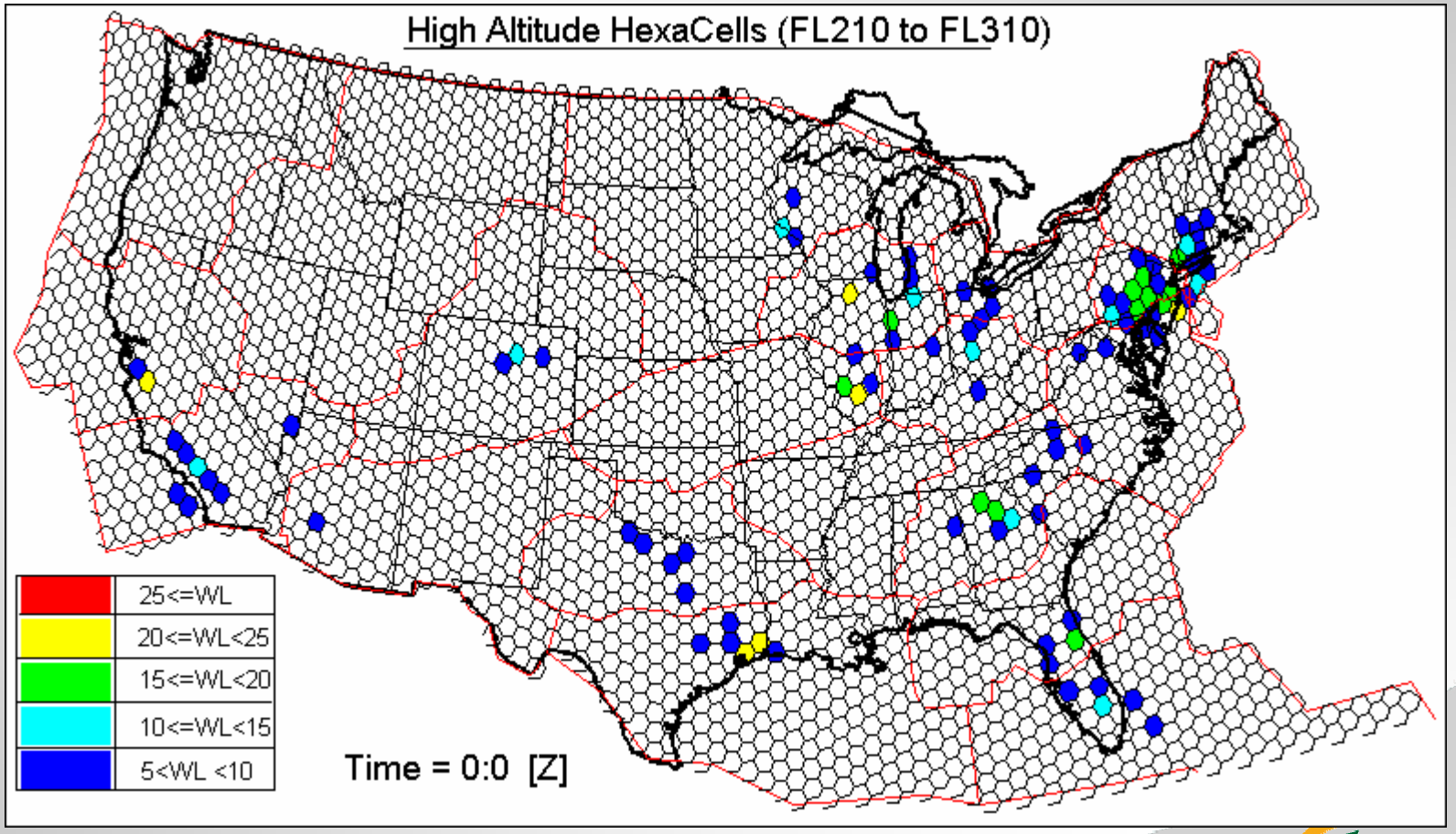

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Hex-cells Clustered to Construct Optimum Center/Sector Boundaries

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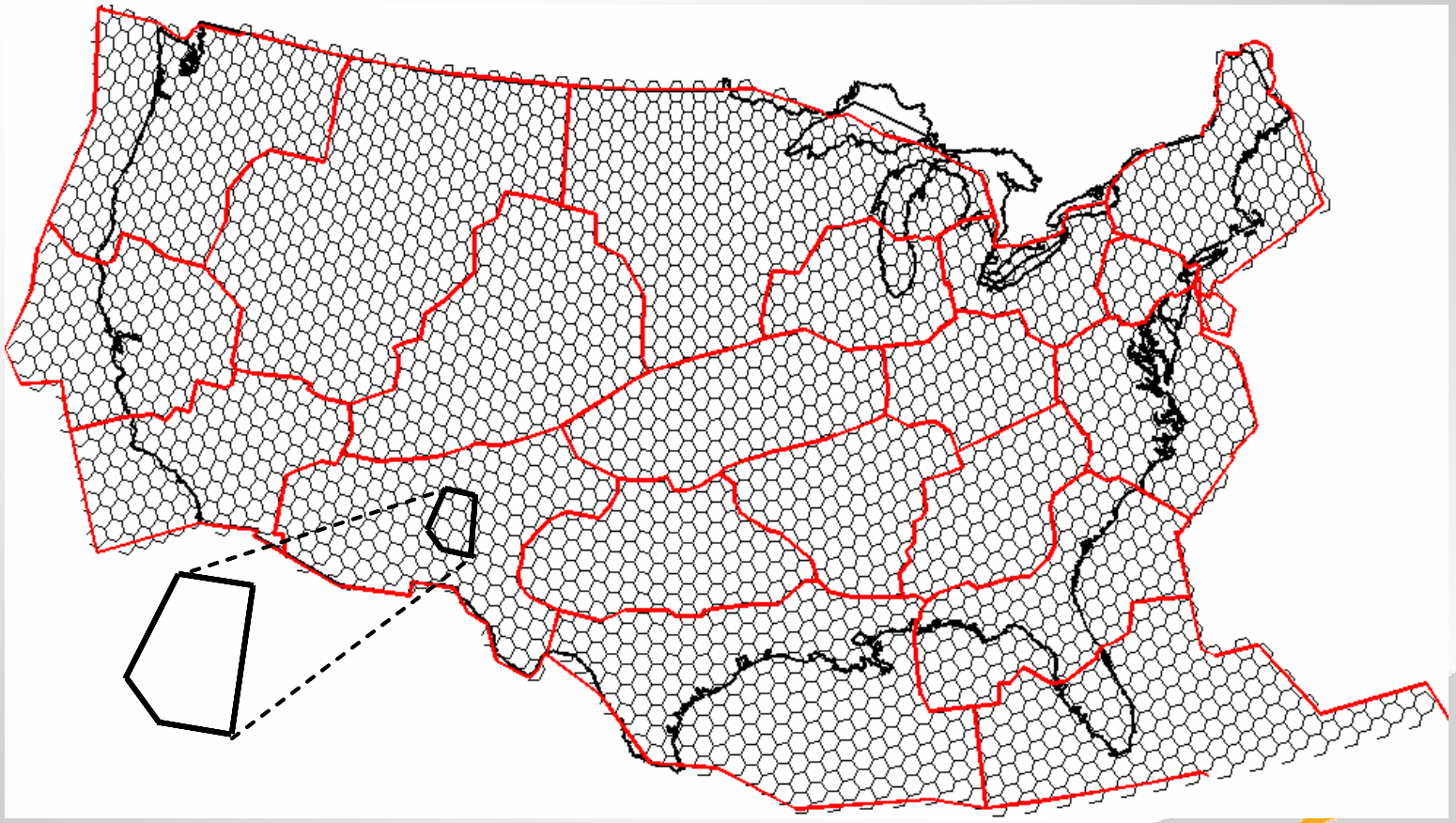

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Clustering Algorithm (summary)

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- **Integer Linear Program (ILP)**
- **Combinatorial minimization problem**
- **For each altitude layer→ (649 × 2,566) =1,665,334 combinatorial variables**

MINIMIZE ***(variation of workload among sectors)***
SUBJECT TO:

- ***sector contiguity***
- ***avoiding highly concave sectors***
- ***number of sectors is limited***
- ***avoid extremely large sectors***
- ***some other ordinary constraints (e.g. sector contiguity, assignment of each hex-cell to a single sector, etc)***

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Preliminary Results of ARTCC Boundary Re-design

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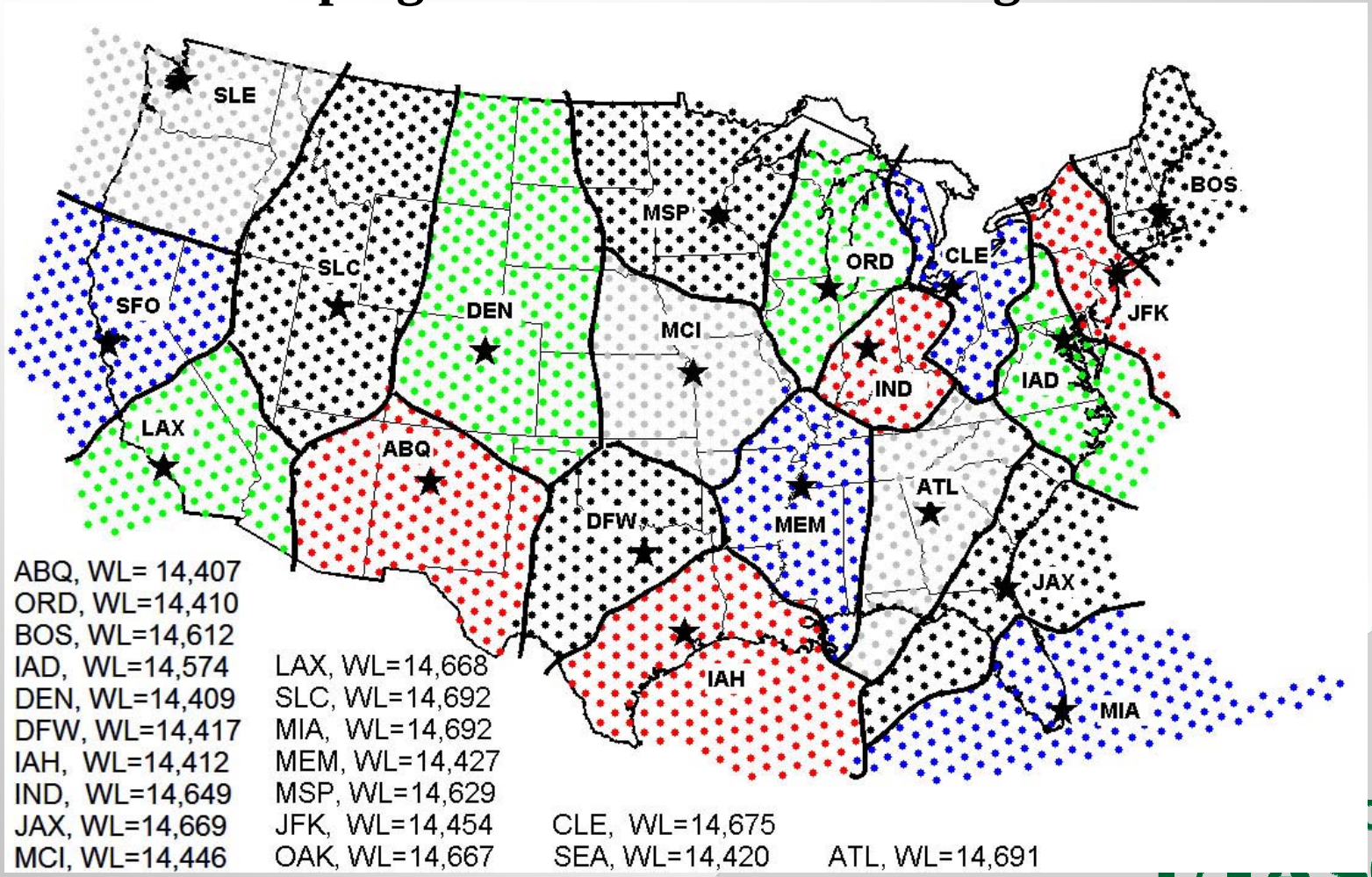
Base case: Keeping 20 Centers and Revising the Boundaries



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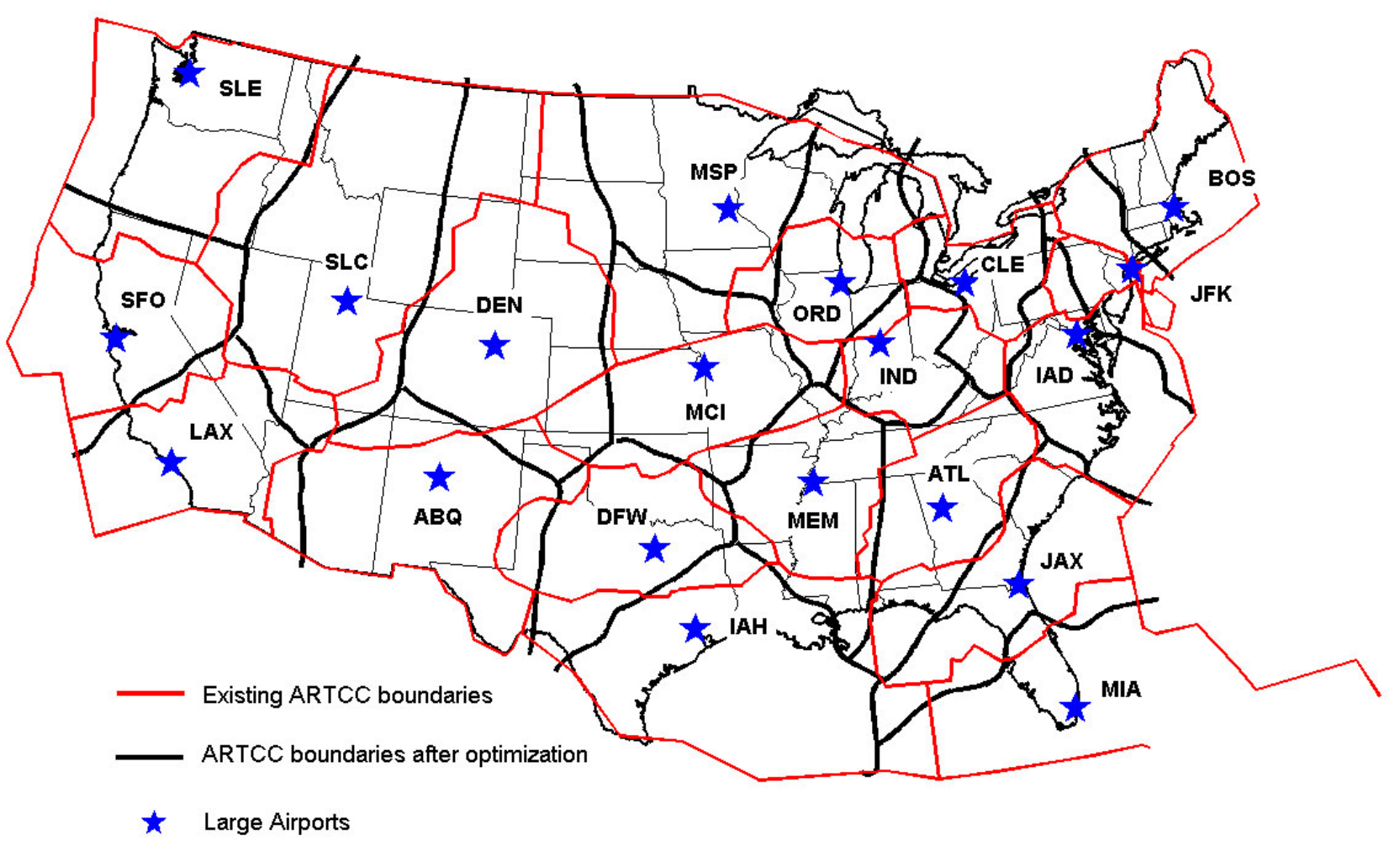
Current vs. Re-defined Boundaries



Results of Center Re-design for Different Number of Operational Centers *(n Selected by the FAA)*

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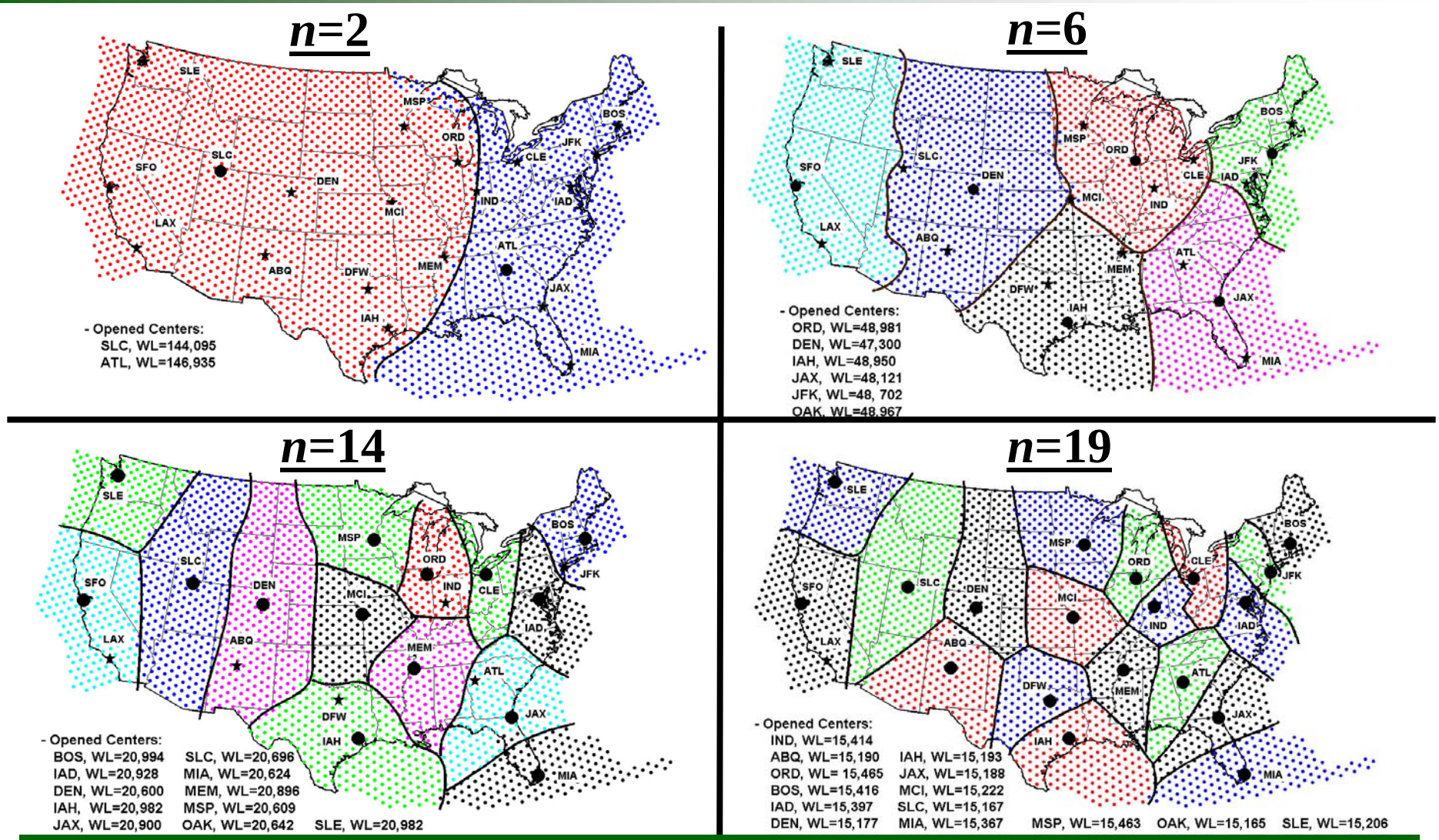
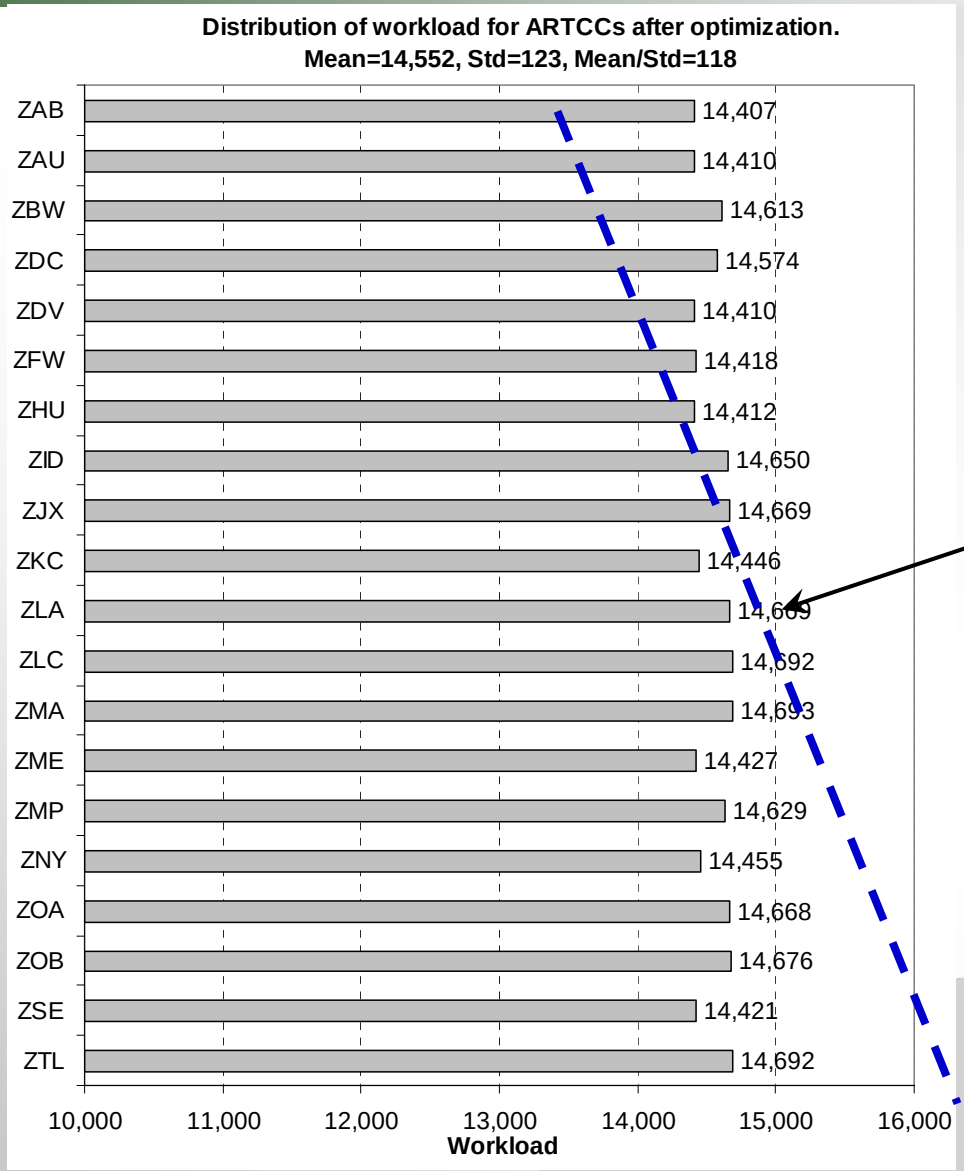


Note: The algorithm decides which Center needs to be opened to achieve optimality

Potential Effect of Optimization in Balancing the Spatial Distribution of Workload



Current Design

Congestion Management by Runway Arrival Time Slot Auction

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Aircraft Down-Gauging Decreasing Transportation Throughput at High Congestion Rates

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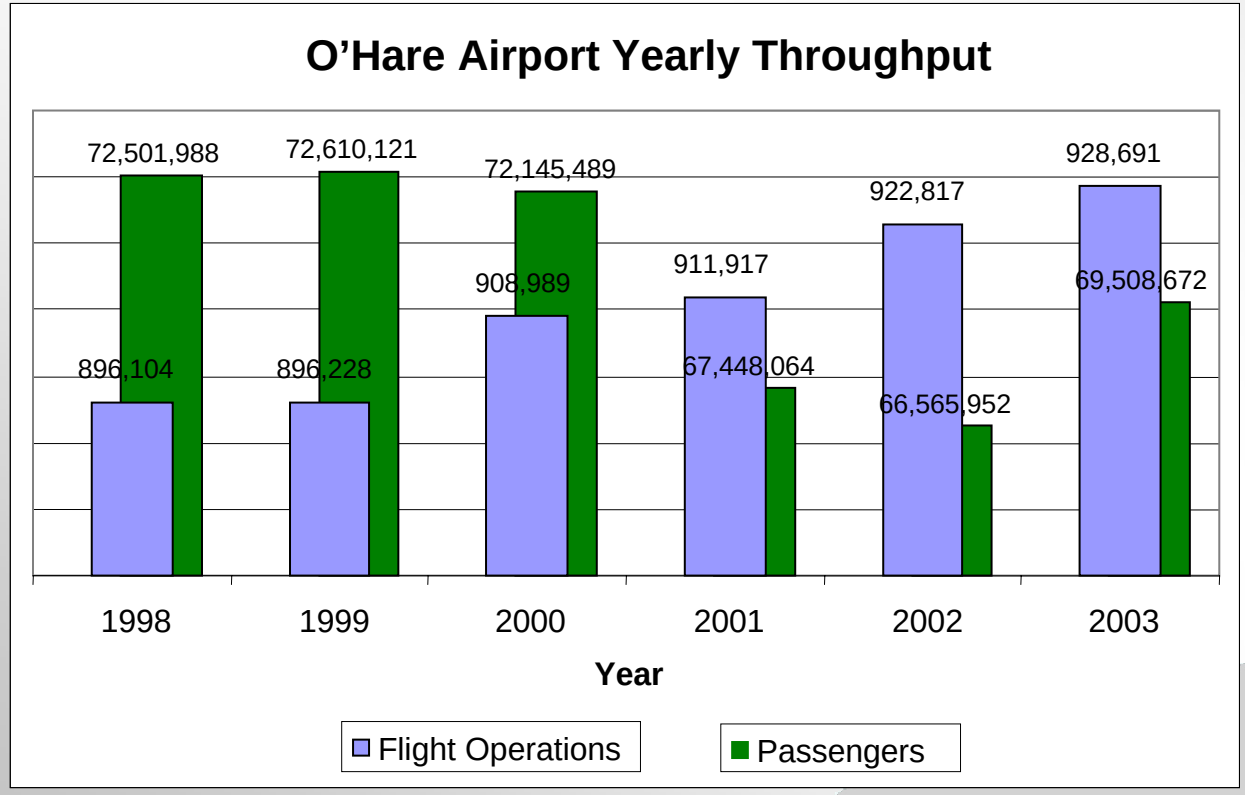
- **Frequency competition reduces seat capacity and increases operating cost**



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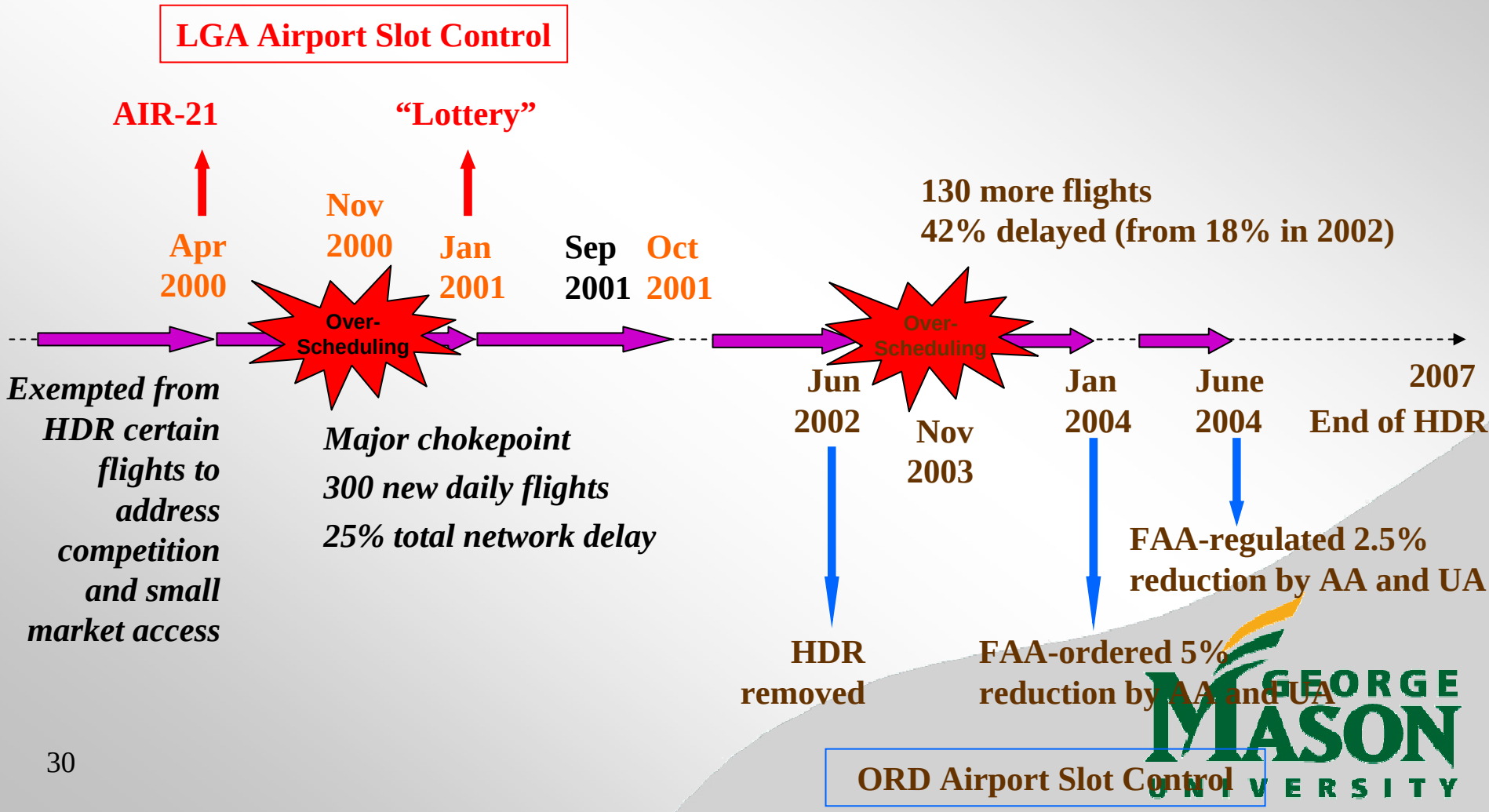
FAA's Congestion Management History



Demand Management Policy Changes Require Simulation Studies

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Great Concern About Key Airport Demand Management Effects on:

- **Airline Economics and Network Scheduling Behavior**
- **FAA Economics and Future Revenue**
- **National Network Connectivity (i.e. Service to Small Communities)**

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Auctions May be Used to Optimize Airport Runway Arrival Time Slot Schedules

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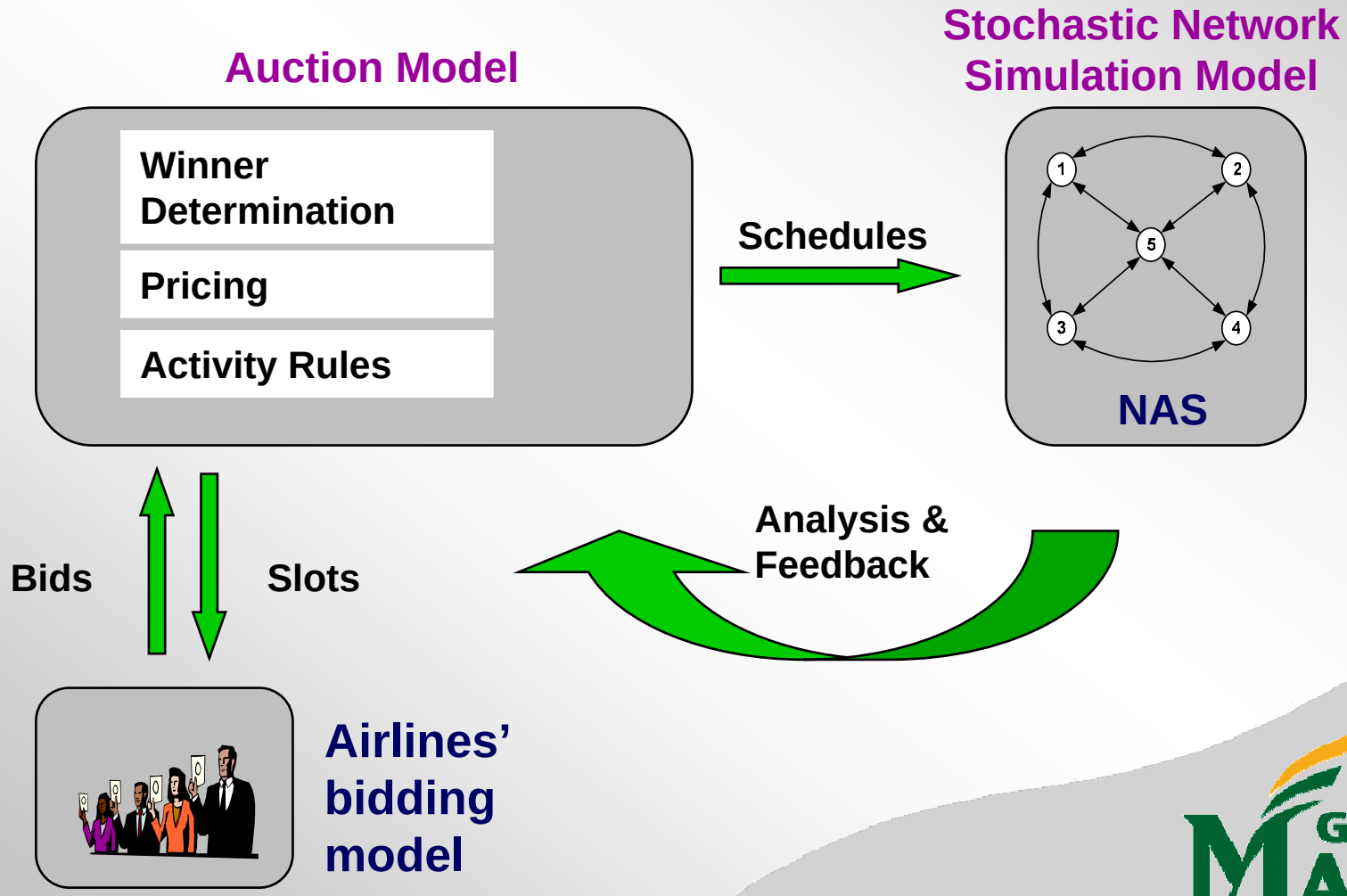

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Simulation of LGA Showing Effect of Auction on Delay Reduction

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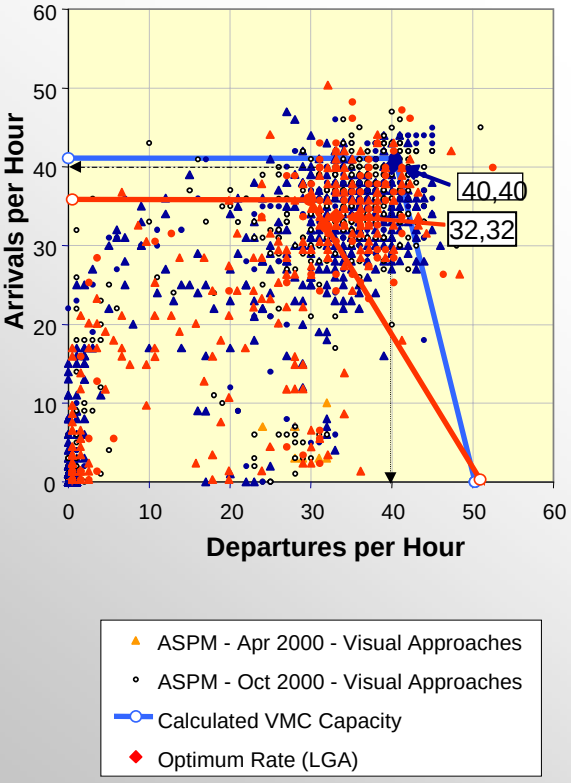
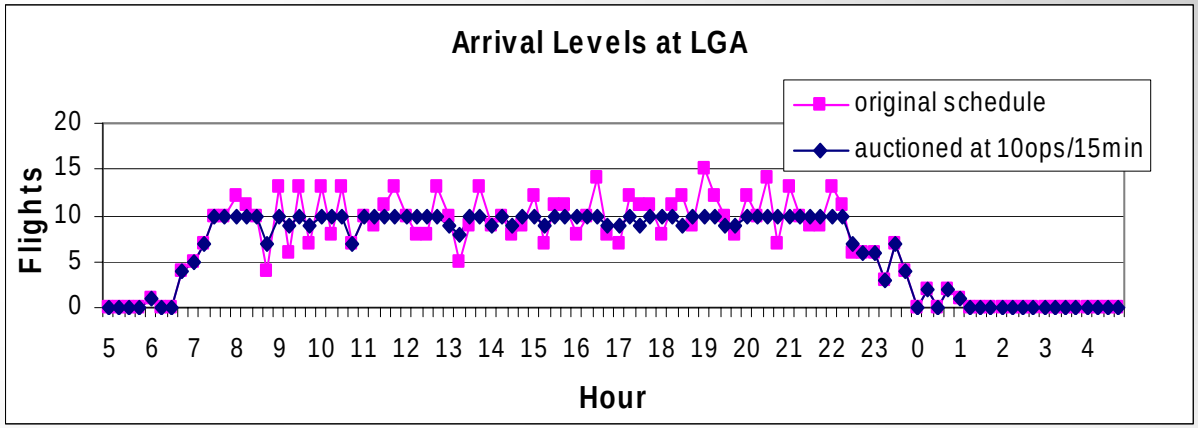
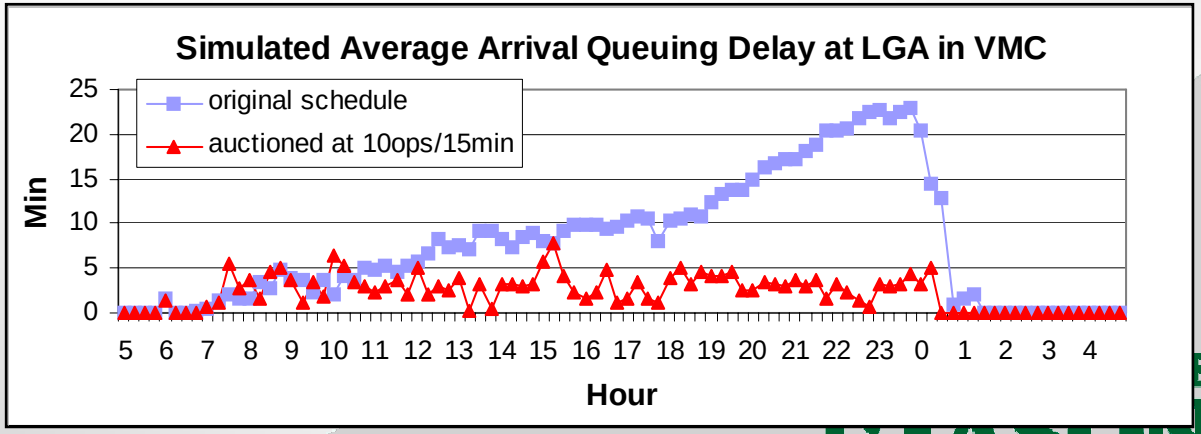
Capacity Benchmark







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Simulation of Auction Effect on ORD Delays

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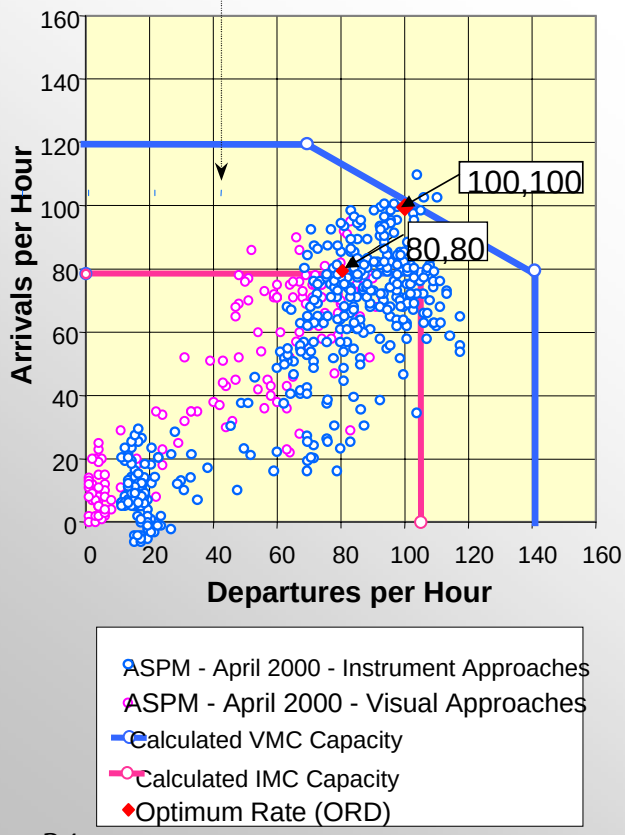
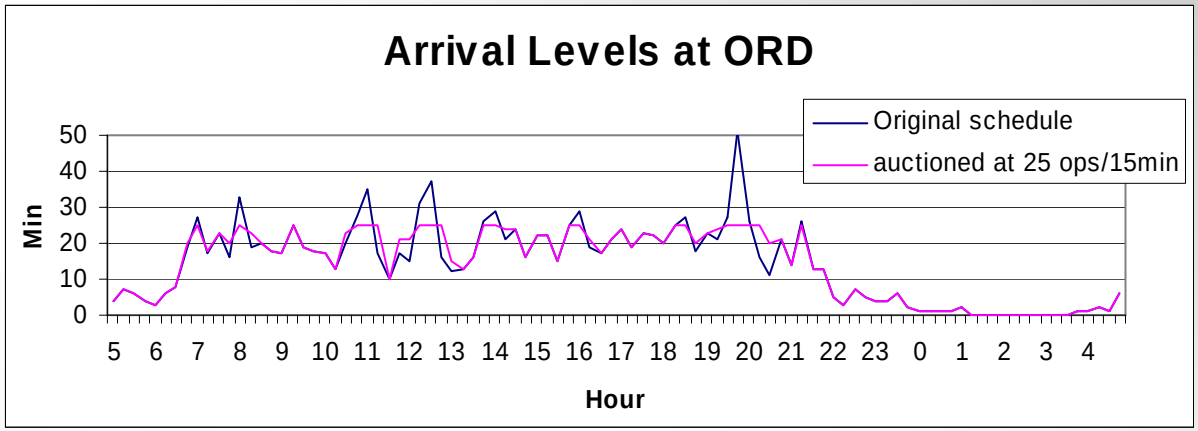
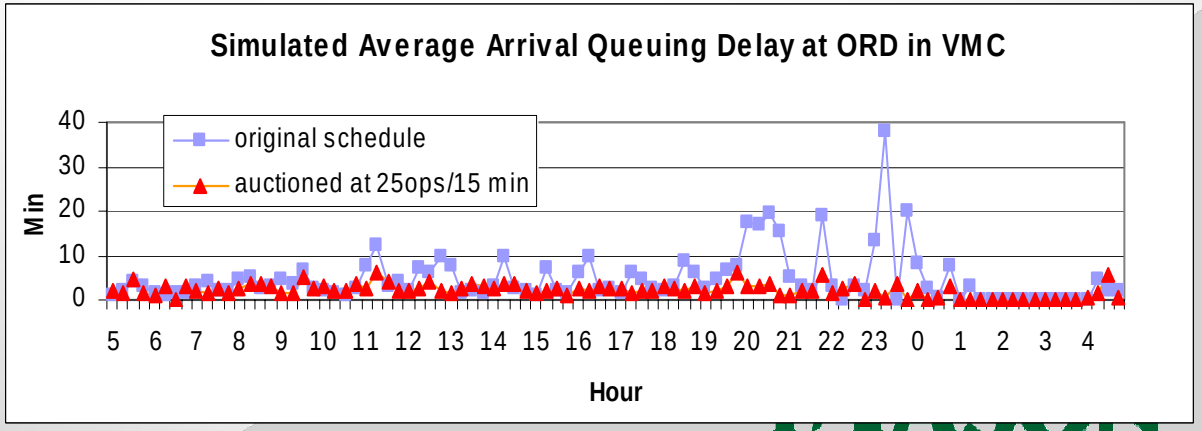
Capacity Benchmark







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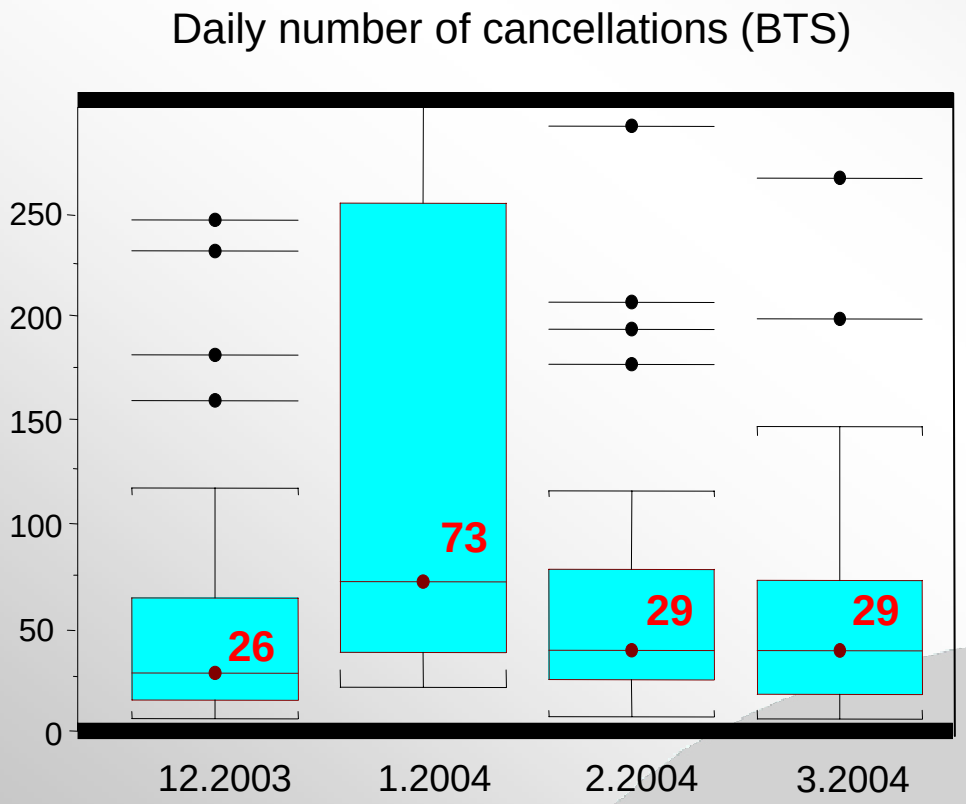
#Flights rerouted vs. #actual cancellations

- **At ORD, 26 flights have to be rerouted by auction**
- **Comparable with actual number of Cancelled Flight (i.e. Transportation Predictability Goal)**



Congestion Management Strategic Games

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Sponsorship: DoT and FAA

Dates:

- **Nov. 3-5, 2004**
- **Feb 24-25, 2005**

Objectives:

- **Study feasibility of auction**
- **Obtain feedback from airlines and FAA**
- **A big milestone for real auction**

Participants:

- **GMU and UMd**
- **NEXTOR Universities: UC Berkley, MIT, and Harvard**
- **DoT, FAA, PANYNJ, Congress, Airlines**
- **NASA AMES as observer**

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Observations on Games to Date

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- **Market Based Demand Management Found better Scheduling Options than Current Administrative Rules**
  - **Airline Behavior Tended to Increase airplane gauge to certain markets**
  - **Relatively small congestion charges had Significant effects on both Delay and Throughput**
  - **Number of time slots to be allocated is a key Issue**
  - **Airline Network Scheduling behavior if Major Hubs were put under CM is Unknown**

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Conclusions

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- **Bayesian network Analysis**
  - **Leading to better nonlinear, stochastic models to be used in network simulations**
  - **Forming the basis for airline and airport specific flight cancellation agent model development**
- **ACES could be used for Center/Sector workload estimation and Center redesign studies**
- **Auction has high potential for congestion management and can be a useful concept for ACES to evaluate**

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Conclusions (cont'd)

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- **Research Support for FAA NAS Strategy Simulator**
  - **System Performance and Economic Performance**
    - **Includes all layers of the network and their supply chain**
  - **Transparent Functions**
    - **Effect of changes in parameters shall be made evident**
    - **Building intuitions in the analyst is most important contribution of the model**
  - **Feedback Loops & Stability Analysis**
    - **Loops provide stability/instability and must be analyzed**
  - **Stochastic Models (mean and variance) where applicable**
    - **Understanding the variability in a stochastic system is as important as understanding the mean**
    - **Reducing the variability provides the platform on which reduction of the mean can take place (Deming, Juran)**
  - **Interact with Industry/Government models (ACES, …)**

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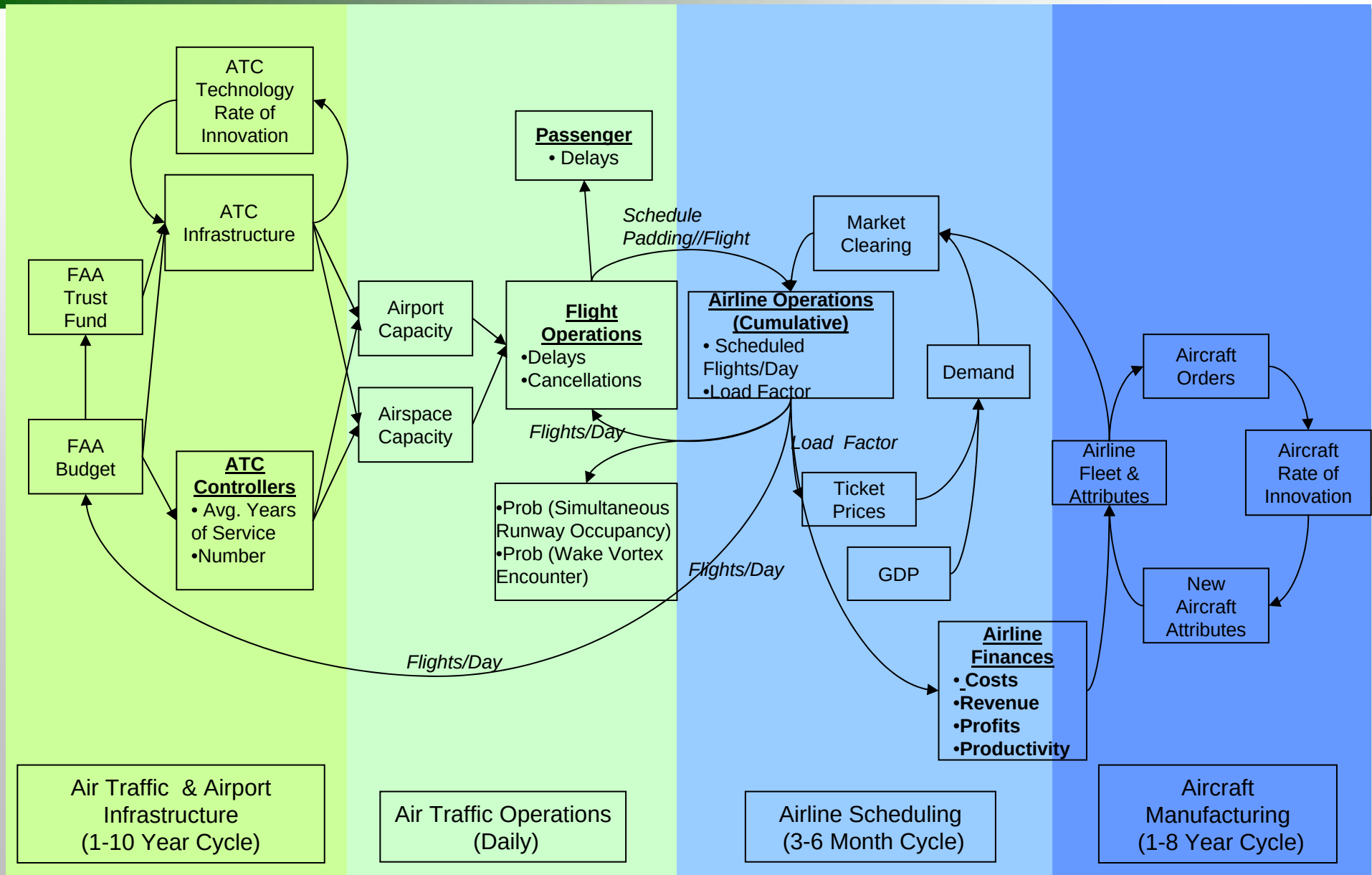
System and Economic Performance



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CATSR

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