Probabilistic Congestion Management

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6th US/Europe Seminar on ATM R&D
Baltimore, MD - 27-30 June 2005
En Route Congestion

Uncertain weather forecasts indicate current and future loss of airspace capacity...

Uncertain traffic forecasts provide airspace demand...

If demand exceeds capacity, delays will occur and safety may be compromised.

Given the uncertainty: When should air traffic be restricted? Which flights should be affected?

Congestion Alerts

Air traffic control sector
Predicting Sector Congestion: Sources of Uncertainty

- Initial Predictions
- Sector Capacity Distribution
- Actual Positions
- Sector Transit Prediction Error Distributions
- Predicted Positions
- Departure Error Distributions
- Cancellation Distributions
- Pop-up Distributions
- Reroute/Amendment Distributions
En Route TFM Today: Deterministic Congestion Management

Sector 02

<table>
<thead>
<tr>
<th>Time</th>
<th>Demand</th>
<th>Capacity</th>
<th>ETMS Red Alert (all aircraft airborne)</th>
<th>ETMS Yellow Alert (some pre-departure flights)</th>
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Projected Weather Impact
Future Sector Congestion Plan View

- Uncertain Traffic Demand
- Uncertain Weather Forecast

Sector 02

- $p(\text{congestion}) > 75\%$
- $p(\text{congestion}) > 50\%$

Time (Future): 16:40
Probabilistic Future Sector Demand and Capacity Graph

Sector 02

- Demand
- Capacity

Time:
- 15:00
- 16:00
- 17:00
- 18:00

Probability of congestion > 75%
Probability of congestion > 50%
Probability of congestion < 50%

Impact of Weather Forecast Uncertainty
Managing Congestion to an Acceptable Level of Risk (Probability)

Sector 02

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- Probability of congestion > 75%
- Probability of congestion > 50%
- Probability of congestion < 50%

Impact of Weather Forecast Uncertainty
Forecasting Demand Uncertainty: Aggregate Model

• First approach: model variability in peak demand predictions
  – Based on empirical measurements under low traffic conditions
    • 6 months of observed predicted and actual peak counts
  – Statistical modeling based on critical factors:
    • Primary sector traffic type (departure, arrival, en route, mixed)
    • Baseline number of flights predicted (Total)
    • Number of those flights still on the ground (Proposed)
    • Look-Ahead Time (LAT)

• Model is composed of closed-form distributions with variable parameters (mean, standard deviation)
  – See paper for complete model details
Aggregate Demand Model Example

En Route Sectors with Total=8 and Proposed=2

- LAT=30 minutes
- LAT=60 minutes
- LAT=120 minutes

En Route Sectors with Total=8, LAT=60 Minutes

- Proposed=2
- Proposed=4
- Proposed=6
Applications and Limitations

• Applications
  – Improved congestion displays, with prediction bias removed and better classification of alerts
  – Testing of automated congestion resolution algorithms – model is very fast to compute
  – Can be readily adjusted to reflect changing traffic characteristics

• Limitations
  – Not aircraft-specific
  – Not sector-specific

• A more detailed model is being developed.
Monte-Carlo Simulation Model

One Monte-Carlo Simulation Trial:

1. Remove “no-shows”
2. Apply unanticipated routing and altitude changes
3. Apply departure prediction errors
4. Apply sector transit prediction errors
5. Add “pop-ups”

New set of predicted trajectories, with uncertainties applied

“N” simulation trials...

Calculate Statistics

Probabilistic Sector Demand Predictions

Probabilistic Displays, Decision Analysis, Real-Time DS Automation, …

Deterministic Sector Demand Predictions

Baseline Trajectory Predictions
Example Results: En Route Sector - Two Prediction Horizons

Histograms of Monte Carlo results

LAT=30 minutes

Baseline Prediction: 5

LAT=105 minutes

Baseline Prediction: 12
Displaying Traffic Demand Uncertainty

Monte Carlo Counts Histogram for ZAB45
Sector Capacity is Complex and Uncertain

- Need a better way to measure and predict capacity to support congestion management when considering uncertainty.
  - measure *flows* rather than *aircraft* considering the time frame and uncertainty involved in TFM
  - capture the impact of convective weather
Applying Probabilistic Forecasts: Risk Management Decision Loop

- Traffic Demand Model
- Problem Identification (Congestion Monitoring)
- Sector Capacity Model
- Congestion Probabilities, Problem Constraints
- Risk Management Decision Maker (When to Act)
- Problem Solving Criteria (Congestion Threshold, Allowable Strategies, Cost Function)
- Resolution Strategy Developer (Which Flights to Affect, What Actions to Take)
- Current Resolution Strategy, Potential Future Resolutions

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Conclusion

• En route congestion management in the U.S. today is highly manual and very conservative, due to uncertainty.
  – This is a major roadblock to anticipated air traffic demand growth.

• The concept proposed here can address this need
  – Uncertainty is explicitly used
  – Targeted, incremental solutions are recommended

• Much work remains!
  – Initial resolution algorithms have been prototyped, based on initial demand uncertainty model
  – Sector capacity prediction model is not yet complete
  – NAS user collaboration modes are still being explored
  – Major human factors issues must be addressed