Airport Capacity Prediction Considering Weather Forecast Uncertainty

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Objectives

• Develop an analytical model that explicitly incorporates weather forecasts, and their uncertainty, in estimating airport capacity
  • Focus on providing decision support for strategic Air Traffic Flow Management (ATFM) planning and long-term probabilistic effects

• Validate probabilistic airport capacity predictions against actual arrival and departure throughput

• Investigate the impact of different methods of representing weather uncertainty on airport capacity predictions
Weather Uncertainty Representation

- **Statistical error modeling**
  - Empirical parameter fitting for wind, ceiling & visibility by airport

\[
U_c = \alpha_u(a, \tau)U_{raw} + \beta_u(a, \tau)
\]

\[
V_c = \alpha_v(a, \tau)V_{raw} + \beta_v(a, \tau)
\]

- **Time-lagged HRRR**
  - With or without spatial filtering
    (latter provides for smoother PDFs)

<table>
<thead>
<tr>
<th>Airport</th>
<th>March 2011</th>
<th>August 2011</th>
</tr>
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<tbody>
<tr>
<td>ATL</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>DFW</td>
<td>0.1</td>
<td>2.0</td>
</tr>
<tr>
<td>ORD</td>
<td>-0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>DEN</td>
<td>-0.3</td>
<td>0.4</td>
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<table>
<thead>
<tr>
<th>Airport</th>
<th>October 2011</th>
<th>December 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATL</td>
<td>-0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>DFW</td>
<td>0.0</td>
<td>-0.4</td>
</tr>
<tr>
<td>ORD</td>
<td>-0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>DEN</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Increasing Look-ahead Time

The height of each bar represents an estimated probability of achieving this capacity value.

Arrivals

Increasing capacity

Ensemble Weather Forecasts
- Ceiling & Visibility
- Surface Winds
- Precipitation & Echo Tops

Predicted Demand
- Hourly Arrival & Departure Counts
- Aircraft Types

Integrated Airport Capacity Model (IACM)

Terminal Capacity Model (TCM)

Airfield Capacity Model (ACM)
- Runway Configuration Estimator (RCE)
- Runway Capacity Model (RCM)

Multi-criteria Capacity Forecast Integrator (MCFI)

Airport Adaptation
- Layout and Geometry
- Runway Configurations
- Runway Occupancy Times
- Approach Speeds

Operational Standards & Procedures
- Arrival and Departure Separations
- Ceiling and Visibility Thresholds
- Wake Vortex Separations
- Crosswind and Tailwind Thresholds
Sensitivity Analysis and Validation Studies

• Parameters studied:
  • Final approach separation buffer $b_{MIT}$
  • Separation buffer for departure release $b_{REL}$
  • Separation buffer for consecutive departure release $b_{DEP}$

• ASPM arrival and departure counts

• Types of weather inputs
  • METAR observations
  • Deterministic forecasts
  • Deterministic forecast and forecast error models (Monte Carlo)
  • Ensemble forecasts (time-lagged HRRR)

• Scatterplots and Theil inequality coefficients based on IACM outputs
  • Grouped by operation type (arrivals and departures)
  • Grouped by airport meteorological conditions: Visual Meteorological Conditions (VMC), Marginal VMC (MVMC), and Instrument Meteorological Conditions (IMC)
Weather Days

• **Selection of Days**
  - Representative cases for IACM simulations
  - Multiple airports & seasons

• **Weather Constraints**
  - Seasonal variation
    - Low in summer
    - High in fall & winter
  - Geographical variation
    - ORD high in Feb & Dec

• **Clear & Calm Days**
  - Seasonal variation
    - High in summer & fall
  - Geographical variation
    - ORD high in Jul, Aug & Oct
Qualitative Validation

Maximum combined rate estimated by IACM is 250

FAA 2004 Airport Capacity benchmark defines the optimum capacity of 237

Actual observed arrival and departure throughput never exceeded 205 flight in 2011

Alternative arrivals and departures capacity (Point 3) for ATL on 07/06/2011 11:00Z for runway configuration 26R 27L 28 | 26L 27R 28
Stratification due to meteorological conditions

Outliers

Deterministic

Forecast Error Models

Ensemble
The impact of the final approach separation buffer $b_{MIT}$ (left) and separation buffer for consecutive departure release $b_{DEP}$ on the accuracy of arrival and departure capacity predictions for VMC conditions.
Validation with Scaled 2011 Demand

- Determine ratio of current demand to baseline demand
  - Use mean of 2007 & 2008 demand as baseline
- Multiply computed prediction with ratio to get scaled prediction

Scaling brings prediction closer to actual throughput

Unscaled prediction

Scaled prediction
Conclusions

- IACM explicitly integrates weather information and its uncertainty to estimate airport capacity
- It supports various types of weather inputs and operational constraints
- Validation study performed to evaluate predicted accuracy of IACM for ATL
- Validation results and operational feedback indicate that IACM produces fairly accurate predictions of theoretical maximum airport capacity

IACM has also been used to support Airside Capacity Enhancement study for several South African airports
Future Research

• Extending the set of supported airport to the Core 30 airports

• Developing web interface for real-time airport capacity prediction

• Enhancing the analytical models for airports with complex runway geometries

• Integrating Terminal Capacity Model with Airfield Capacity Model to predict convective weather impact on terminal airspace/corner posts
Theil Statistics

• Quantify airport capacity prediction accuracy using Theil inequality coefficient:

• It can be decomposed into 3 components:
  
  • Bias or error in central tendency $T_m$

  • Unequal variation $T_s$

  • Incomplete covariation $T_c$

$$T = \frac{\sum_i (P_i - A_i)^2}{\sum_i A_i^2}$$

$$T_m = \frac{(\bar{P} - \bar{A})^2}{\frac{1}{n} \sum_i^n (P_i - A_i)^2}$$

$$T_s = \frac{(s_P - s_A)^2}{\frac{1}{n} \sum_i^n (P_i - A_i)^2}$$

$$T_c = \frac{2(1 - r)s_ps_A}{\frac{1}{n} \sum_i^n (P_i - A_i)^2}$$

Source: (Sterman 1984)