Modeling Flight Delays and Cancellations at the National, Regional and Airport Levels in the United States

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Motivation

• Weather is the major cause of delay in the National Airspace System (NAS)

• Four situations

• Develop baseline relating delay, cancellations and other NAS performance metrics to the weather conditions to improve Traffic Flow Management
Results

• Developed flight delay and cancellation models at the national, regional and airport levels

• Expected number of aircraft impacted by weather good proxy for delay

• Different models for summer and winter

• All metrics can be estimated to same level of accuracy

• FAA delay databases are complementary

• Neural Network models perform slightly better
Outline

• Background
• Objectives
• Modeling/Estimation of Metrics
  – Regression Models
  – Neural Network Models
• Results
• Conclusions and Future Work
Background

- Databases
- Airspace Performance Metrics
- Weather Impacted Traffic Index
Databases

• FAA Operations Network (OPSNET)
  – Data available from 1990
  – Daily values
  – 45 airports
  – Total national delay

• Aviation System Performance Metrics (ASPM)
  – Data available from 2000
  – Every 15 minutes
  – 75 airports
  – Total schedule-based and flight-plan based arrival delays, departure delays, airborne delays, flight cancellations

• Paper uses data from 2005-2008
NAS Performance Metrics

Default Customer View

APF Dashboard
For Wednesday, August 13, 2008

Welcome Joe User
Today is Thursday, August 14, 2008

Days 1 2 3 4

With Last 8 Days

ATM Minutes Last 8 Days

ON Time & On Time Gas Arrivals Last 8 Days

OpsNET Delays Last 8 Days

Hold Minutes Last 8 Days

Delay, MIT, Predictability Last 8 Days

Efficiency Last 8 Days

<table>
<thead>
<tr>
<th>Customer View</th>
<th>ATO View</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAS</td>
<td>Service Area</td>
</tr>
</tbody>
</table>

Print | Help | Log Out | Customize
NAS Performance Metrics

Default Customer View

APF Dashboard
For Wednesday, August 13, 2008

Welcome Joe User
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Grid-based Weather Impacted Traffic Index (WITI)

**Aircraft positions**

**Severe weather**

\[ WITI(k) = \sum_{1 \leq j \leq m} \sum_{1 \leq i \leq n} T_{i,j}(k)W_{i,j}(k) \]
National Weather Index (NWX)

• Models weather and congestion at airports and terminal area

• Three components
  – En-route WITI (E-WITI), representing convective weather impact on major flows between city pairs
  – Terminal WITI (T-WITI), representing weather impact on major airports
  – Airport Queuing Delay (Q-Delay), representing surface and terminal-airspace weather impact on major airports in a non-linear fashion
Objectives

- Develop and compare NAS performance metric models based on FAA operational traffic databases
  - Different metrics
  - Impact of databases
  - Approach
    - Linear regression models
    - Neural networks models
Modeling/Estimation of Metrics

- WITI at the national level \((X)\)
- WITI at the Center level \((X_p)\)
- Performance metric \((\delta)\)
- Models
  - Linear Regression (LR) \[ \delta = \alpha X + \beta \]
  - Multiple Linear Regression (MLR) \[ \delta = \sum_{p=1}^{20} \alpha_p X_p + \beta_p \]
  - Neural Networks \[ \delta = f(X_p) \]
Performance of Regression Models

OPSNET Total Delay
(100K minutes)

Number of Flight Cancellations

Observed Delay

Observed Flight Cancellations

Estimate

Estimate
Performance of Regression Models

<table>
<thead>
<tr>
<th>Type of Metric</th>
<th>Correlation Coefficient</th>
<th>Root Mean Squared Error</th>
<th>Mean Absolute Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPSNET delay (LR)</td>
<td>0.71</td>
<td>32,700 minutes</td>
<td>26,600 minutes</td>
</tr>
<tr>
<td>OPSNET delay (MLR)</td>
<td>0.77</td>
<td>31,200 minutes</td>
<td>24,500 minutes</td>
</tr>
<tr>
<td>Scheduled delay</td>
<td>0.75</td>
<td>99,200 minutes</td>
<td>74,300 minutes</td>
</tr>
<tr>
<td>Flight Cancellations</td>
<td>0.77</td>
<td>131 flights</td>
<td>94 flights</td>
</tr>
</tbody>
</table>

- Regression models perform a good job of accounting for the impact of weather on delays and flight cancellations.
- For systems with demand-capacity imbalance, growth in delay is non-linear.
Nonlinear Models

Single Linear Model (SLM)

Three-Piece Linear Model (3PLM)

Weather → WITI Computations

Traffic → Center WITIs

Exact Classification

Predicted Classification

Inputs $X_p$

Hidden Layer

Output Layer

Performance Metric $\delta$ (Target)
Performance of National Model

OPSNET Total Delay

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Correlation Coefficient</th>
<th>Root Mean Squared Error</th>
<th>Mean Absolute Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>.71</td>
<td>32,700 minutes</td>
<td>26,600 minutes</td>
</tr>
<tr>
<td>MLR</td>
<td>.77</td>
<td>31,200 minutes</td>
<td>24,500 minutes</td>
</tr>
<tr>
<td>Neural Network</td>
<td>.88</td>
<td>30,000 minutes</td>
<td>23,300 minutes</td>
</tr>
</tbody>
</table>

Flight Cancellation

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Correlation Coefficient</th>
<th>Root Mean Squared Error</th>
<th>Mean Absolute Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>.73</td>
<td>146 flights</td>
<td>106 flights</td>
</tr>
<tr>
<td>MLR</td>
<td>.77</td>
<td>131 flights</td>
<td>94 flights</td>
</tr>
<tr>
<td>Neural Network</td>
<td>.88</td>
<td>131 flights</td>
<td>93 flights</td>
</tr>
</tbody>
</table>

- Neural Network models perform slightly better
• Models using NWX perform slightly better and the difference varies with the estimation method
• Neural networks and MLR trained using 2005-2007 data and tested using 2008 data
• Higher correlation during summer
• Lower correlation in winter may be due to higher number of cancellations on days with heavy snow, very low ceilings/visibility
**Airport Delay Models using Regression Analysis**

- Modeled 34 major airports in the U.S.
- Good delay estimates for ORD, ATL,..
- Delay at major airports in Eastern U.S not influenced by NWX in the neighboring Centers

<table>
<thead>
<tr>
<th>Airport</th>
<th>$\gamma_{LR}$</th>
<th>$\gamma_{MLR}$</th>
<th>$\gamma_{MLR}/\gamma_{LR} - 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORD</td>
<td>0.743</td>
<td>0.803</td>
<td>0.08</td>
</tr>
<tr>
<td>ATL</td>
<td>0.752</td>
<td>0.777</td>
<td>0.03</td>
</tr>
<tr>
<td>EWR</td>
<td>0.640</td>
<td>0.725</td>
<td>0.13</td>
</tr>
<tr>
<td>PHL</td>
<td>0.764</td>
<td>0.805</td>
<td>0.06</td>
</tr>
<tr>
<td>DFW</td>
<td>0.577</td>
<td>0.646</td>
<td>0.12</td>
</tr>
<tr>
<td>JFK</td>
<td>0.618</td>
<td>0.670</td>
<td>0.08</td>
</tr>
<tr>
<td>LGA</td>
<td>0.685</td>
<td>0.723</td>
<td>0.06</td>
</tr>
<tr>
<td>LAX</td>
<td>0.195</td>
<td>0.496</td>
<td>1.54</td>
</tr>
<tr>
<td>IAH</td>
<td>0.684</td>
<td>0.725</td>
<td>0.06</td>
</tr>
<tr>
<td>DEN</td>
<td>0.550</td>
<td>0.664</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Concluding Remarks

- WITI-based models provide a good basis for estimating delay due to convective weather
- Estimation/Modeling of performance metrics resulting from the use of the two databases are complementary
- Models have higher correlation during summer than during winter
- For all metrics, neural networks produce higher correlation and reduced errors than regression methods
Future Work

• WITI as a measure of delay to evaluate different TFM policies
  – Airspace Flow Program procedures
  – What-if scenarios
  – Optimization
• Inclusion of additional factors from the operational databases