Computation of Aggregate Delay Using Center-based Weather Impacted Traffic Index

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Outline

• Motivation
• Objective
• Weather Impacted Traffic Index
• Delay Prediction Models
• Classification of a day into delay categories
• Results
• Concluding Remarks
Motivation

- Traffic Flow Management initiatives in response to surface & enroute weather are the major cause of National Airspace System (NAS) delays
- Relate the delay performance to the weather conditions
  - Assessment using baseline data
  - Prediction based on weather forecast
Objectives

- Develop a NAS delay estimation models based on expected traffic, and surface and enroute weather
  - Linear Model
  - Three-piece Linear Model
- Compare the accuracy of the two estimation models
Weather Impacted Traffic Index (WITI)

\[ WITI(k) = \sum_{i=1}^{n} \sum_{j=1}^{m} T_{i,j}(k) W_{i,j}(k) \]

Aircraft positions grid

Severe weather grid
Delay modeled as a linear combination WITI features
Delay Prediction Models
**NAS Delay Estimation**

**Model**

\[
\begin{align*}
\text{Features} & = \begin{bmatrix}
  f_1(1) & f_2(1) & \cdots & f_r(1) \\
  f_1(2) & f_2(2) & \cdots & f_r(2) \\
  \vdots & \vdots & \ddots & \vdots \\
  f_1(s) & f_2(s) & \cdots & f_r(s)
\end{bmatrix} \\
\text{Delay} & = \begin{bmatrix}
  w_1 \\
  w_2 \\
  \vdots \\
  w_r
\end{bmatrix} \\
& = \begin{bmatrix}
  d(1) \\
  d(2) \\
  \vdots \\
  d(s)
\end{bmatrix}
\end{align*}
\]

**Weights**

\[w = (F^T F)^{-1} F^T d\]

**Delay estimate**

\[\hat{d}(p) = \begin{bmatrix}
  f_1(p) & f_2(p) & \cdots & f_r(p)
\end{bmatrix} w\]
Piece-Wise Linear Modeling

\[
F = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix}, \quad d = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix}, \quad w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}
\]

\[
w_i = (F_i^T F_i)^{-1} F_i^T d_i
\]

\[
\hat{d}_i = F_i w_i
\]

- Three linear models covering recorded delays
  - 0 to Low, Low to Medium, and Medium to High regions

Nextor 2007
Delay Estimation Models

Single Linear Model (SLM)

Three-Piece Linear Model (3PLM)

Weather

Traffic

WITI Computations

WITI

Exact Classification

Predicted Classification

Center WITIs
Classification of a day into delay categories
Average Center WITIs by Delay Category

Low

Medium

High
Normalized average center WITIs for 2004, 2005 and 2006
## Correlation of Center WITI with OPSNET delays

<table>
<thead>
<tr>
<th># of Center</th>
<th>Center Names</th>
<th>Correlation Coefficient</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>ZNY</td>
<td>0.59</td>
</tr>
<tr>
<td>2</td>
<td>ZNY ZOB</td>
<td>0.68</td>
</tr>
<tr>
<td>3</td>
<td>ZNY ZAU ZDC</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>ZNY ZAU ZOB ZDC</td>
<td>0.75</td>
</tr>
<tr>
<td>6</td>
<td>ZNY ZAU ZOB ZDC ZID ZTL</td>
<td>0.76</td>
</tr>
<tr>
<td>9</td>
<td>ZNY ZAU ZOB ZDC ZID ZTL ZHU ZFW ZME</td>
<td>0.73</td>
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</tbody>
</table>
Average and standard deviation of total WITI values using 4-center configuration.
Validation of delay classification using August 2006 data

<table>
<thead>
<tr>
<th>Date #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</thead>
<tbody>
<tr>
<td>Actual Delay (min)</td>
<td>9,126</td>
<td>9,843</td>
<td>12,844</td>
<td>24,667</td>
<td>26,290</td>
<td>29,612</td>
<td>33,955</td>
</tr>
<tr>
<td>Category in PLM</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Predicted Category</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
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<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Delay (min)</td>
<td>37,139</td>
<td>37,979</td>
<td>39,220</td>
<td>44,972</td>
<td>46,500</td>
<td>49,812</td>
<td>50,259</td>
</tr>
<tr>
<td>Category in PLM</td>
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<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
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<tr>
<td>Predicted Category</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
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<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Delay (min)</td>
<td>51,010</td>
<td>53,207</td>
<td>55,564</td>
<td>55,858</td>
<td>59,547</td>
<td>79,459</td>
<td>88,077</td>
</tr>
<tr>
<td>Category in PLM</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Predicted Category</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
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<table>
<thead>
<tr>
<th>Date #</th>
<th>22</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>26</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Delay (min)</td>
<td>93,109</td>
<td>106,606</td>
<td>126,004</td>
<td>133,257</td>
<td>143,173</td>
<td>175,804</td>
</tr>
<tr>
<td>Category in PLM</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Predicted Category</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
Results
Delay estimation for August 2006 using single linear model

![Scatter plot showing observed vs. predicted delays in August 2006. The plot includes a linear trend line.](image-url)
Delay estimation for August 2006 using predicted delay classification
Comparison of delay estimation between single linear model and 3-piece linear model
Delay estimation for August 2006

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Correlation Coefficient</th>
<th>Standard Deviation (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM</td>
<td>0.89</td>
<td>20,400</td>
</tr>
<tr>
<td>3-PLM with exact classification</td>
<td>0.94</td>
<td>12,530 14,820 22,826</td>
</tr>
<tr>
<td>3-PLM with predicted classification</td>
<td>0.93</td>
<td>13,769 15,039 22,826</td>
</tr>
</tbody>
</table>

- Three-piece linear model provides a better estimate of aggregate delay
Concluding Remarks

- First attempt to successfully classify days into delay categories based on Center WITI values.
- Developed an integrated method to estimate NAS aggregate delay as a function of weather and traffic.
- Three-piece linear model provides significantly better estimates of delay.
- Future research
  - Improvement of delay classification using different techniques.
  - Use of three-dimensional information in the computation of WITI.
  - Use of Aviation System Performance Metrics (ASPM).
Additional Viewgraphs
NOWRAD Weather Level 3-6 with CIWS Grid
CIWS Weather Echotop 0626_2006_0005
Computation of WITI

- Count of all flying aircraft impacted by NOWRAD weather levels 3 through 6
- Count of all flying aircraft impacted by CIWS(2D) weather levels 3 through 6
- Count of all flying aircraft impacted by CIWS(3D) weather levels 3 through 6