Predicting the Operational Acceptance of Route Advisories

Antony Evans (Crown Consulting, Inc.)
Paul Lee (NASA Ames)
Reroute Advisories

Return Capture Fix

Flight Plan Routing

Auxiliary Waypoint

Reroute Advisory

Maneuver Start Sector

Maneuver Start Point

24 min
Dynamic Weather Routes (DWR)

ATC Coordinator

Dispatcher

Pilot

Air Traffic Controller
Motivation

- Historical usage required for ATC route acceptance
- Other factors also contribute to ATC acceptance
- **Objective**: Develop a predictor of operational acceptability for route advisories

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<table>
<thead>
<tr>
<th></th>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>Rejected</td>
<td>69%</td>
<td>31%</td>
</tr>
</tbody>
</table>

ATC Response to DWR Route Advisory (DWR trial, 2014)

Route Observed in Flight Plan Amendment Data (Jun-Aug 2015)

Evans, et al. (2016)
Approach

Identify features
- Literature review
- Subject matter experts

Extract data
- ATC accepted routes
- ATC rejected routes

Data Mining
- Binary classifier

Validation
Features

- Historical count (full route)
- Historical count (by segment)
- Maneuver start sector demand/capacity
- Maneuver start sector over capacity
- Number sectors over capacity
- Max demand to capacity ratio
- Number downstream sectors
- Direct routing or via aux. waypoint
- Time to exit maneuver start sector
- Distance between maneuver start point and sector exit
Data

Usage
ASDI Data

Flight Plan Amendments

Common Routing Tables

Feature Extraction
DWR Trial Data (ZFW and adjacent Centers)

DWR Advisories
Flight Plan Amendments

Future ATM Concepts Evaluation Tool (FACET)

Usage

Sector Counts etc.
Classifying Routings

No flight plan amendment implemented within 30 min

Flight plan amendment

ATC Rejected (9%)
ATC Acceptable (13%)
ATC Rejected (31%)
ATC Acceptable (47%)
Model Development

- **Feature Selection**
  - Forward search through 10 features

- **Model Selection**
  - Logistic regression
  - Decision tree
  - Support Vector Machine (SVM) with sigmoid kernel
  - Random forest
  - Adaptive Boost (AdaBoost)

- **Parameter Selection**
  - e.g., Number of trees

- **Model Validation**
  - Nested cross-validation
Feature Selection

- Forward Search with Random Forest, 10-fold cross validation
- 317 to 544 observations – 40% to 48% Rejected; 60% to 52% Accepted

MSS – Maneuver Start Sector
Features

- Historical count (full route)
  - Historical count (route segment)

- Maneuver start sector demand/capacity
- Maneuver start sector over capacity

- Number downstream sectors
- Direct routing or via aux. waypoint

- Time to exit maneuver start sector
- Distance between maneuver start point and sector exit

- Number sectors over capacity
- Max demand to capacity ratio
Model Selection

- 7 features
- 10-fold cross validation
- 317 observations – 48% Rejected; 52% Accepted

Parameter Selection: 40 trees
Model Validation

- 7 features, Random Forest, 40 trees
- Nested 10-fold cross validation
- 317 observations – 48%Rejected (positive); 52% Accepted (negative)

<table>
<thead>
<tr>
<th>Observed (Actual)</th>
<th>Predicted</th>
<th>Rejected</th>
<th>Accepted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rejected</td>
<td>61%</td>
<td>39%</td>
<td></td>
</tr>
<tr>
<td>Accepted</td>
<td>22%</td>
<td>78%</td>
<td></td>
</tr>
</tbody>
</table>

Model Accuracy: 70%

Receiver Operating Characteristic Curve

Discrimination threshold = 70%
Conclusions

• Developed a predictor of operational acceptability for route advisories:
  – Accuracy of 74%
  – Route rejection predicted at rate of 88%

• Relevant model features:
  – Historical usage
  – Timing/location of request in maneuver start sector
  – Number of downstream sectors
  – Direct routing or via auxiliary waypoints
  – Demand to capacity levels in maneuver start sector

• Best performing model is Random Forest with 40 trees
Future Work

• Extension to other airspace
  – Trial data for NAS Constraint Evaluation and Notification Tool (NASCENT)

• Improve features
  – Include weather impact on maneuver start sector capacity
  – Add other features, e.g., Center information
  – May use voice recordings to identify timing and details of pilot requests to ATC
Questions?
Back-up Slides
DWR Use and Estimated Actual Savings

January 2013 to September 2014

40% of dispatcher accepted routes see actual savings

Traditional Model Development

Dataset

Development Set

Training Set

Evaluation Set

Test Set
Nested Cross Validation

Dataset

Development Set

Evaluation Set

Training Set

Test Set
Feature Selection: Forward Search

- Random Forest, 10-fold cross validation
- 317 to 544 observations – 40% to 48% Rejected (positive); 60% to 52% Accepted (negative)
Feature Selection: Forward Search

- Method: Random Forest, 40 trees, 10-fold cross-validation
- Positive (Rejected or Modified) 40%; Negative (Accepted) 60%
- Observations: between 317 and 544, depending on features included

<table>
<thead>
<tr>
<th>Feature Set with highest F-Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Concatenation Count,</td>
</tr>
<tr>
<td>- Number of Downstream Sectors,</td>
</tr>
<tr>
<td>- Distance to Exit MSS,</td>
</tr>
<tr>
<td>- MSS Over Capacity</td>
</tr>
<tr>
<td>- Time to Exit MSS,</td>
</tr>
<tr>
<td>- Direct Routing</td>
</tr>
<tr>
<td>- MSS Demand/Capacity Ratio</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model F-Score</th>
<th>1 Feature</th>
<th>2 Features*</th>
<th>3 Features*</th>
<th>4 Features*</th>
<th>5 Features*</th>
<th>6 Features*</th>
<th>7 Features*</th>
<th>8 Features*</th>
<th>9 Features*</th>
<th>10 Features*</th>
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<tbody>
<tr>
<td>Full Count</td>
<td>0.648</td>
<td>0.695</td>
<td>0.753</td>
<td>0.771</td>
<td>0.764</td>
<td>0.766</td>
<td>0.801</td>
<td>0.775</td>
<td>0.767</td>
<td>0.780</td>
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<tr>
<td>Concat. Count</td>
<td>0.674</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Direct Routing</td>
<td>0.387</td>
<td>0.597</td>
<td>0.705</td>
<td>0.775</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>No. Sectors Over</td>
<td>NA</td>
<td>0.599</td>
<td>0.693</td>
<td>0.743</td>
<td>0.746</td>
<td>0.766</td>
<td>0.809</td>
<td>0.783</td>
<td>0.797</td>
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<tr>
<td>Max D/C Ratio</td>
<td>0.255</td>
<td>0.664</td>
<td>0.751</td>
<td>0.773</td>
<td>0.769</td>
<td>0.789</td>
<td>0.772</td>
<td>0.784</td>
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<tr>
<td>MSS Over Capacity</td>
<td>NA</td>
<td>0.583</td>
<td>0.674</td>
<td>0.744</td>
<td>0.758</td>
<td>0.782</td>
<td>0.815</td>
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<tr>
<td>MSS D/C Ratio</td>
<td>0.381</td>
<td>0.660</td>
<td>0.749</td>
<td>0.758</td>
<td>0.773</td>
<td>0.796</td>
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<tr>
<td>No. Dwnstrm. Sectors</td>
<td>0.484</td>
<td>0.667</td>
<td>0.755</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Time to Exit MSS</td>
<td>0.497</td>
<td>0.719</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Dist. to Exit MSS</td>
<td>0.467</td>
<td>0.665</td>
<td>0.719</td>
<td>0.761</td>
<td>0.789</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

* Includes feature set with highest F-Score from previous column
Feature Selection

- Forward Search, using a Random Forest and 10-fold cross-validation
- Feature Set with highest F-Score:
  - Hist. Count by Segment,
  - Number of Downstream Sectors,
  - Distance to Exit Maneuver Start Sector,
  - Maneuver Start Sector Over Capacity.

```
Receiver Operating Characteristic Curve
```

```
Hist. Count by Segment
+Time to Exit MSS
+No. Dwnstrm Sectors
+Direct Routing
+Dist. to Exit MSS
+MSS D/C Ratio
+MSS Over Capacity
```
Model Selection

- 7 features
- 10-fold cross validation
- 317 observations – 48% Rejected (positive); 52% Accepted (negative)

Accuracy (50% discrimination threshold)

Parameter Selection: 40 trees
Model Selection

- 10-fold cross-validation
- 317 observations – 48% Positive (Rejected or Modified); 52% Negative (Accepted)

<table>
<thead>
<tr>
<th></th>
<th>Logistic Regression</th>
<th>Decision Tree</th>
<th>SVM</th>
<th>Random Forest</th>
<th>AdaBoost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.73</td>
<td>0.74</td>
<td>0.69</td>
<td>0.82</td>
<td>0.78</td>
</tr>
<tr>
<td>Misclassification Error</td>
<td>0.27</td>
<td>0.26</td>
<td>0.31</td>
<td>0.18</td>
<td>0.22</td>
</tr>
<tr>
<td>True Positive Rate/Recall</td>
<td>0.71</td>
<td>0.75</td>
<td>0.63</td>
<td>0.84</td>
<td>0.76</td>
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<tr>
<td>True Negative Rate</td>
<td>0.75</td>
<td>0.72</td>
<td>0.73</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>Precision</td>
<td>0.73</td>
<td>0.71</td>
<td>0.69</td>
<td>0.79</td>
<td>0.77</td>
</tr>
<tr>
<td>F-score</td>
<td><strong>0.72</strong></td>
<td><strong>0.73</strong></td>
<td><strong>0.66</strong></td>
<td><strong>0.82</strong></td>
<td><strong>0.77</strong></td>
</tr>
</tbody>
</table>

Receiver Operating Characteristic Curve

- Logistic Regression
- Decision Tree
- SVM
- Random Forest
- AdaBoost
Parameter Selection: Number of Weak Learners

- Random Forest, with 10-fold cross validation
- 317 observations – 48% Positive (Rejected or Modified); 52% Negative (Accepted)
- Parameter value with highest F-Score: 40 trees

Receiver Operating Characteristic Curve
Feature Selection

- **Method**: Forward Search, training a Random Forest with 40 trees, using 10-fold cross-validation
- **Metric**: F-Score
- **Observations**: between 317 and 544, depending on features included
- **Data Balancing**: Positive (Rejected or Modified) 40%; Negative (Accepted) 60%

- **Feature Set with highest F-Score (0.815):**
  - Hist. Count by Segment,
  - Number of Downstream Sectors,
  - Distance to Exit MSS,
  - MSS Over Capacity

- **Receiver Operating Characteristic Curve**

  - Hist. Count by Segment
  - Time to Exit MSS
  - Number of Downstream Sectors
  - Direct Routing
  - Distance to Exit MSS
  - MSS Demand/Capacity Ratio
  - MSS Over Capacity
Model Selection

- **Method:** 10-fold cross-validation
- **Observations:** 317
- **Data Balancing:** Positive (Rejected or Modified) 48%; Negative (Accepted) 52%
- **Features:** Hist. Count by Segment, Time to Exit MSS, No. Downstream. Sectors, Direct Routing, Dist. to Exit MSS, MSS D/C Ratio, MSS Over Cap.

<table>
<thead>
<tr>
<th></th>
<th>Logistic Regression</th>
<th>Decision Tree</th>
<th>SVM</th>
<th>Random Forest</th>
<th>AdaBoost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>0.732</td>
<td>0.735</td>
<td>0.685</td>
<td>0.817</td>
<td>0.776</td>
</tr>
<tr>
<td><strong>Misclassification Error</strong></td>
<td>0.268</td>
<td>0.265</td>
<td>0.315</td>
<td>0.183</td>
<td>0.224</td>
</tr>
<tr>
<td><strong>True Positive Rate</strong></td>
<td>0.711</td>
<td>0.750</td>
<td>0.632</td>
<td>0.842</td>
<td>0.763</td>
</tr>
<tr>
<td><strong>True Negative Rate</strong></td>
<td>0.752</td>
<td>0.721</td>
<td>0.733</td>
<td>0.794</td>
<td>0.788</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td>0.725</td>
<td>0.713</td>
<td>0.686</td>
<td>0.790</td>
<td>0.768</td>
</tr>
<tr>
<td><strong>F-score</strong></td>
<td><strong>0.718</strong></td>
<td><strong>0.731</strong></td>
<td><strong>0.658</strong></td>
<td><strong>0.815</strong></td>
<td><strong>0.766</strong></td>
</tr>
<tr>
<td><strong>Area Under ROC</strong></td>
<td>0.818</td>
<td>0.767</td>
<td>0.770</td>
<td>0.886</td>
<td>0.864</td>
</tr>
<tr>
<td><strong>Average Precision</strong></td>
<td>0.776</td>
<td>0.687</td>
<td>0.735</td>
<td>0.870</td>
<td>0.826</td>
</tr>
</tbody>
</table>
Parameter Selection: Number of Weak Learners

- **Method:** Random Forest, with 10-fold cross validation
- **Data Balancing:** Positive (Rejected or Modified) 48%; Negative (Accepted) 52%
- **Features:** Hist. Count By Segment, Time to Exit MSS, No. Dwnstrm. Sectors, Direct Routing, Dist. to Exit MSS, MSS D/C Ratio, MSS Over Cap.

<table>
<thead>
<tr>
<th>Number of Trees:</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.798</td>
<td>0.801</td>
<td>0.817</td>
<td>0.798</td>
<td>0.798</td>
<td>0.795</td>
<td>0.808</td>
<td>0.792</td>
<td>0.785</td>
</tr>
<tr>
<td>Misclassification Error</td>
<td>0.202</td>
<td>0.199</td>
<td>0.183</td>
<td>0.202</td>
<td>0.202</td>
<td>0.205</td>
<td>0.192</td>
<td>0.208</td>
<td>0.215</td>
</tr>
<tr>
<td>True Positive Rate</td>
<td>0.829</td>
<td>0.816</td>
<td>0.842</td>
<td>0.809</td>
<td>0.822</td>
<td>0.816</td>
<td>0.829</td>
<td>0.803</td>
<td>0.796</td>
</tr>
<tr>
<td>True Negative Rate</td>
<td>0.770</td>
<td>0.798</td>
<td>0.794</td>
<td>0.798</td>
<td>0.776</td>
<td>0.776</td>
<td>0.788</td>
<td>0.782</td>
<td>0.776</td>
</tr>
<tr>
<td>Precision</td>
<td>0.768</td>
<td>0.780</td>
<td>0.790</td>
<td>0.778</td>
<td>0.772</td>
<td>0.770</td>
<td>0.783</td>
<td>0.772</td>
<td>0.766</td>
</tr>
<tr>
<td>F-score</td>
<td>0.797</td>
<td>0.797</td>
<td><strong>0.815</strong></td>
<td>0.794</td>
<td>0.796</td>
<td>0.792</td>
<td><strong>0.805</strong></td>
<td>0.787</td>
<td><strong>0.781</strong></td>
</tr>
<tr>
<td>Area Under ROC</td>
<td>0.877</td>
<td>0.871</td>
<td>0.886</td>
<td>0.875</td>
<td>0.870</td>
<td>0.878</td>
<td>0.883</td>
<td>0.874</td>
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<tr>
<td>Average Precision</td>
<td>0.860</td>
<td>0.820</td>
<td>0.870</td>
<td>0.833</td>
<td>0.844</td>
<td>0.854</td>
<td>0.863</td>
<td>0.840</td>
<td>0.835</td>
</tr>
</tbody>
</table>

Receiver Operating Characteristic Curve

- **Number of Trees:** 20, 30, 40, 50, 60, 70, 80, 90, 100
Parameter Selection: Number of Weak Learners

- **Method**: Random Forest, with 10-fold cross validation
- **Metric**: F-Score
- **Observations**: 317
- **Data Balancing**: Positive (Rejected or Modified) 48%; Negative (Accepted) 52%
- **Features**: Hist. Count by Segment, Time to Exit MSS, No. Downstream Sectors, Direct Routing, Dist. to Exit MSS, MSS D/C Ratio, MSS Over Cap.

- Parameter value with highest F-Score (0.815):
  - 40 trees

![Receiver Operating Characteristic Curve](image)
Model Validation

- Random Forest, 7 features, 40 trees
- Nested 10-fold cross validation
- 317 observations – 48% Rejected (positive); 52% Accepted (negative)

Model Accuracy: 74%
Model Validation

- **Method**: Random Forest, with 10-fold nested cross validation
- **Observations**: 317
- **Data Balancing**: Positive (Rejected or Modified) 40%; Negative (Accepted) 60%

<table>
<thead>
<tr>
<th>Nested Cross-Validation</th>
<th></th>
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<tbody>
<tr>
<td>Accuracy</td>
<td>0.744</td>
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<tr>
<td>Misclassification Error</td>
<td>0.256</td>
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<tr>
<td>True Positive Rate/Recall</td>
<td>0.875</td>
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<tr>
<td>True Negative Rate</td>
<td>0.624</td>
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<tr>
<td>Precision</td>
<td>0.682</td>
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<tr>
<td><strong>F1 Score</strong></td>
<td><strong>0.767</strong></td>
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<tr>
<td>Area Under ROC</td>
<td>0.814</td>
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<tr>
<td>Average Precision</td>
<td>0.742</td>
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</tbody>
</table>

Receiver Operating Characteristic Curve
Comparison to One-Class Classification

- **Method**: 10-fold cross-validation
- **Observations**: 317
- **Data balancing**: Positive (Rejected or Modified) 48%; Negative (Accepted) 52%
- **Features**: Hist. Count by Segment, Time to Exit MSS, No. Downstream Sectors, Direct Routing, Dist. to Exit MSS, MSS D/C Ratio, MSS Over Capacity

<table>
<thead>
<tr>
<th></th>
<th>Random Forest</th>
<th>Two-Class SVM</th>
<th>One-Class SVM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>0.817</td>
<td>0.685</td>
<td>0.558</td>
</tr>
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<td><strong>Misclassification Error</strong></td>
<td>0.183</td>
<td>0.315</td>
<td>0.442</td>
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<tr>
<td><strong>True Positive Rate/Recall</strong></td>
<td>0.842</td>
<td>0.632</td>
<td><strong>0.211</strong></td>
</tr>
<tr>
<td><strong>True Negative Rate</strong></td>
<td>0.794</td>
<td>0.733</td>
<td>0.879</td>
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<tr>
<td><strong>Precision</strong></td>
<td>0.790</td>
<td>0.686</td>
<td>0.615</td>
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<tr>
<td><strong>F Score</strong></td>
<td><strong>0.815</strong></td>
<td><strong>0.658</strong></td>
<td><strong>0.314</strong></td>
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</table>