PRESENTATION
Alexander Vanwelsenaere

MASTER THESIS
ACADEMIC PAPER
Effect of Pop-Up Flights on Extended Arrival Manager

ATM R&D SEMINAR
Seattle (WA), USA
June 2017

Supervisors
Jacco Hoekstra - TU Delft
Joost Ellerbroek - TU Delft
Evert Westerveld - ATC NL
Introduction

- Limited size and capacity of TMA
- Delay absorption outside TMA: speed reduction, vectoring and holding stacks
- Arrival Management (AMAN) assist ATC in managing arriving traffic
Introduction

- Schiphol TMA: limited size & capacity
- Arriving routes to Amsterdam Schiphol Airport (AMS)
- 3 IAFs: SUGOL – RIVER – ARTIP
- Research focuses on AMS
Arrival Manager (AMAN)

- **Key Modules:**
  - Trajectory Predictor
  - Scheduler
  - (Advisory Module)

- **Working Principle:**
  1. Trajectory Predictor: **ETA** (at runway)
  2. Scheduler: **STA** (at runway)
  3. Trajectory Predictor: **EAT** (at IAF)
  4. Trajectory Predictor: **ETO** (at IAF)
  5. Air Traffic Control: At IAF, match **ETO** with **EAT**

AMAN not used within TMA

**Abbreviations:**
- ETA = Estimated Time of Arrival
- STA = Scheduled Time of Arrival
- EAT = Expected Approach Time
- ETO = Estimated Time Over
### Example:

<table>
<thead>
<tr>
<th>Callsign</th>
<th>ETA (Airport)</th>
<th>STA (Airport)</th>
<th>Delay</th>
<th>ETO (IAF)</th>
<th>EAT (IAF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUD01</td>
<td>12:00</td>
<td>12:00</td>
<td>0'</td>
<td>11:50</td>
<td>11:50</td>
</tr>
<tr>
<td>TUD02</td>
<td>12:01</td>
<td>12:02</td>
<td>1'</td>
<td>11:51</td>
<td>11:52</td>
</tr>
<tr>
<td>TUD03</td>
<td>12:02</td>
<td>12:04</td>
<td>2'</td>
<td>11:52</td>
<td>11:54</td>
</tr>
</tbody>
</table>

**ETA** = Estimated Time of Arrival  
**STA** = Scheduled Time of Arrival  
**ETO** = Estimated Time Over  
**EAT** = Expected Approach Time
Extended Arrival Manager (E-AMAN)

- Fragmented airspace
- Arrival management should take place across borders
Extended Arrival Manager (E-AMAN)

- Benefits
  - Fuel Efficiency
  - Predictability and ATC Task Load

- Technical Challenges
  - Trajectory Prediction Errors
  - Pop-Up Flights

Focus
Pop-Up Flights
Pop-Up Occurrence Analysis

E-AMAN
200 nm horizon
(370 km)
Pop-Up Occurrence Analysis

<table>
<thead>
<tr>
<th>Airport</th>
<th>Location</th>
<th>120 nm Pop-Up Ratio</th>
<th>200 nm Pop-Up Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHAM</td>
<td>Amsterdam Schiphol</td>
<td>1.8%</td>
<td>10.8%</td>
</tr>
<tr>
<td>EDDF</td>
<td>Frankfurt</td>
<td>3.4%</td>
<td>15.0%</td>
</tr>
<tr>
<td>EGLL</td>
<td>Heathrow</td>
<td>0.0%</td>
<td>5.5%</td>
</tr>
<tr>
<td>LFPG</td>
<td>Paris CDG</td>
<td>0.1%</td>
<td>4.9%</td>
</tr>
<tr>
<td>EDDM</td>
<td>Munich</td>
<td>1.7%</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

- Research focuses on AMS
Need for a tool

Effect of Pop-Up Flights on E-AMAN

- Pop-up flights potentially cause big issues
  - Occurrence
  - Effect?
  - Mitigation?

We need a tool!
AMAN Research Simulator (ARSIM)
ARSIM

- Model AMAN/E-AMAN for Amsterdam Schiphol Airport in BlueSky:
  - Trajectory Predictor
  - Scheduler
  - Speed And Route Advisor (SARA)
    - Up to 10% speed reduction
    - Route advisories: vectoring and holding
Experiments
# Experiment I – Effect Pop-Up Flights

- **Effect of Pop-Up Flights on AMAN and E-AMAN**

- **Independent variables:**
  - AMAN Freeze Horizon (FH)
  - Pop-Up Scaling

### Conditions

<table>
<thead>
<tr>
<th>Exp. Condition</th>
<th>AMAN FH</th>
<th>Pop-Up Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/100</td>
<td>120 nm</td>
<td>100%</td>
</tr>
<tr>
<td>A/200</td>
<td>AMAN</td>
<td>200%</td>
</tr>
<tr>
<td>E/0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/100</td>
<td>200 nm</td>
<td>100%</td>
</tr>
<tr>
<td>E/200</td>
<td>E-AMAN</td>
<td>200%</td>
</tr>
</tbody>
</table>

*Replace pop-up flights with regular traffic (and vice versa) to:
  a) Obtain pop-up scaling
  b) Maintain overall traffic demand in all experiment conditions for given sample*
Experiment I – Set-Up

- Dependent Variables – Overall Performance
  1. Delay energy cost \( \rightarrow \) Delay (Cost)
  2. Position Changes \( \rightarrow \) Sequence Stability
  3. STA revisions \( \rightarrow \) Task Load

Diagram:
- TMA
- AMAN Horizon
Experiment I – Set-Up

- 12 Traffic Samples
  - 3-hour inbound peaks (per sample) to Schiphol Airport (AMS)
  - Summer 2015

- Within-subject experiment design
Experiment I – Analysis

- Delay energy cost – E-AMAN
  ➢ Pop-up flights increase delay (cost)

Main effects test: * (p<0.01)

<table>
<thead>
<tr>
<th>E-AMAN conditions</th>
<th>Z-score [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pop-up flights (0%)</td>
<td></td>
</tr>
<tr>
<td>Normal pop-up occurrence (100%)</td>
<td></td>
</tr>
<tr>
<td>Double pop-up occurrence (200%)</td>
<td></td>
</tr>
</tbody>
</table>

0%  20.7 MJ
100% 21.5 MJ
200% 23.7 MJ

Average of all samples
MJ = Mega Joule

E-AMAN conditions
Experiment I – Analysis

- Position changes – E-AMAN
  - Pop-up flights reduce sequence stability

Main effects test: * (p<0.01)

<table>
<thead>
<tr>
<th>E-AMAN conditions</th>
<th>0%</th>
<th>100%</th>
<th>200%</th>
<th>Average of all samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pop-up flights (0%)</td>
<td>26</td>
<td>41</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>Normal pop-up occurrence (100%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double pop-up occurrence (200%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average of all samples
Experiment I – Analysis

• STA revisions – E-AMAN
  ➢ Pop-up flights increase task load

Main effects test: * (p<0.01)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pop-up flights (0%)</td>
<td>9</td>
</tr>
<tr>
<td>Normal pop-up occurrence (100%)</td>
<td>25</td>
</tr>
<tr>
<td>Double pop-up occurrence (200%)</td>
<td>44</td>
</tr>
</tbody>
</table>

Average of all samples
Experiment I – Conclusions

• **E-AMAN**: for larger pop-up occurrences...
  – Delay (Cost) – increases
  – Sequence Stability – decreases
  – Task Load – increases
  ➢ Pop-up flights have a large and significant negative effect

• **AMAN**: similar tendencies, though smaller and not all significant

• **When extending the horizon today**...
  – Delay (Cost) – delay energy cost reduces by 22%
  – Sequence Stability – position changes increases by factor 6
  – Task Load – STA revisions increases by factor 27
  ➢ Benefits of AMAN horizon extension should be pursued, however mitigation actions are needed
Experiment II – Mitigation Measure

• Alternative scheduler (E-AMAN)
  – Pop-up flights: pre-planned (before departure) along with other aircraft
  – Requires take-off time estimates for pop-up flights

  ➢ Question: take-off estimate accuracy requirement? Achievable?

• Independent variables:
  – Scheduler type
  – Departure time estimate error

<table>
<thead>
<tr>
<th>Exp. Condition</th>
<th>Scheduler</th>
<th>Dep. Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>no pre-planning</td>
<td>NA</td>
</tr>
<tr>
<td>U/0</td>
<td></td>
<td>0 s</td>
</tr>
<tr>
<td>U/120</td>
<td>pre-planning</td>
<td>120 s</td>
</tr>
<tr>
<td>U/180</td>
<td></td>
<td>180 s</td>
</tr>
<tr>
<td>U/300</td>
<td></td>
<td>300 s</td>
</tr>
</tbody>
</table>

Original scheduler

Alternative scheduler

Perfect

Inaccuracies
Experiment II – Analysis

- Delay energy cost
  
  Pre-planning inaccuracies increase delay (cost)

Main effects test: *  
(p<0.05)

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Energy Cost (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>21.5 MJ</td>
</tr>
<tr>
<td>Perfect</td>
<td>21.4 MJ</td>
</tr>
<tr>
<td>2’ error</td>
<td>22.0 MJ</td>
</tr>
<tr>
<td>3’ error</td>
<td>22.3 MJ</td>
</tr>
<tr>
<td>5’ error</td>
<td>22.4 MJ</td>
</tr>
</tbody>
</table>

Average of all samples: 22.2 MJ

MJ = Mega Joule
Experiment II – Analysis

- Position changes
  - Pre-planning inaccuracies reduce sequence stability

Main effects test: * 
(p<0.01)

Baseline 41
Perfect 48
2’error 61
3’ error 62
5’ error 73

Average of all samples

Conditions
Experiment II – Analysis

- STA revisions
  - Perfect pre-planning reduces task load
  - Pre-planning inaccuracies increase task load

Main effects test: * (p<0.01)

- Baseline: 25
- Perfect: 15
- 2’ error: 28
- 3’ error: 31
- 5’ error: 36

Average of all samples

Conditions
Experiment II – Conclusions

**Pre-planning (5’ accuracies), when compared to baseline...**
- Pre-planning (5’ inaccuracies) is outperformed by baseline scheduler
  - Delay (Cost) – tendency of larger cost (not significant)
  - Sequence Stability – position changes increases by 78%
  - Task Load – STA revisions increases by 44%

**Pre-planning (2’ accuracies), when compared to baseline...**
- Pre-planning (2’ inaccuracies) is not outperforming baseline
  - Delay (Cost) & Task Load – tendency of performing worse (not significant)
  - Sequence Stability – position changes increases by 48%

**Perfect pre-planning, when compared to baseline...**
- Perfect pre-planning outperforms baseline
  - Delay (Cost) & Sequence Stability – no significant effect
  - Task Load – STA revisions reduces by 38%

- Pre-planning is only beneficial when estimates are perfectly accurate.
Conclusions

• Horizon current AMAN systems is low. Therefore occurrence of pop-up flights rather limited (less than 2% of all arrivals for Amsterdam Schiphol Airport).

• Pop-up flight occurrence grows in context of E-AMAN (10% of all arrivals to Amsterdam Schiphol Airport).

• Pop-up flights negatively affect E-AMAN, in terms of task load, sequence stability and delay (cost).

• Pre-planning pop-up flights is beneficial: only if pre-departure take-off times are perfectly accurate. Pre-planning is not better: if accuracy deteriorates to 2 minutes or more. Pre-planning is worse: if accuracy deteriorates to 5 minutes or more.
Recommendations

• Similar experiments for other hub and secondary airports.

• Develop AMAN algorithms that plan pop-up flights prior to departure, and – at the same time – deal with their (inherent) uncertainty in an efficient way.

• Integrate novel concepts (e.g. Target Time of Arrival) in the context of AMAN/E-AMAN.
Acknowledgements
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Backup Slides
## Pop-Up Occurrence Analysis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EBAW</td>
<td>Deurne</td>
<td>68</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EBBR</td>
<td>Brussels</td>
<td>85</td>
<td>7</td>
<td>5</td>
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<tr>
<td>EDDF</td>
<td>Frankfurt</td>
<td>198</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>EDDK</td>
<td>Cologne</td>
<td>124</td>
<td>2</td>
<td>3</td>
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<tr>
<td>EDDL</td>
<td>Dusseldorf</td>
<td>96</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>EDDV</td>
<td>Hannover</td>
<td>181</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>EDDW</td>
<td>Bremen</td>
<td>153</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>EDFH</td>
<td>Frankfurt</td>
<td>170</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>EGGW</td>
<td>Luton</td>
<td>191</td>
<td>4</td>
<td>6</td>
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<tr>
<td>EGKB</td>
<td>London</td>
<td>185</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>EGKK</td>
<td>Gatwick</td>
<td>197</td>
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<td>EGLC</td>
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<td>10</td>
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<td>EGMC</td>
<td>Southend</td>
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<td>3</td>
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<td>EGSH</td>
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<td>4</td>
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<td>EGSS</td>
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<td>4</td>
<td>5</td>
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<td>EHEH</td>
<td>Eindhoven</td>
<td>56</td>
<td>NA</td>
<td>NA</td>
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<td>EHGG</td>
<td>Eelde</td>
<td>82</td>
<td>NA</td>
<td>1</td>
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<td>EHRD</td>
<td>Rotterdam</td>
<td>24</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>ELLX</td>
<td>Luxembourg</td>
<td>170</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>78</strong></td>
<td><strong>82</strong></td>
</tr>
</tbody>
</table>
Pop-Up Occurrence Analysis
Eligibility Horizon
Freeze Horizon
Active Advisory Horizon
TMA
FLIGHT A445
TAS = 450 kts
FL350
ETA 14:00
STA 14:00

Earlier STA
STA status: variable -> semi-fixed

At Freeze Horizon
STA status: variable -> semi-fixed

FLIGHT B778
TAS=250 kts
FL50 (climbing)
ETA 14:01
STA 14:02
Effect of Pop-Up Flights on Extended Arrival Manager