ONBOARD

Air Traffic Flow Management Under Uncertainty

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DESCRIPTION OF THE PROJECT
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- Air Traffic Flow Management Uncertainties
  - Weather
  - Unscheduled Demand

- The goal of the ONBOARD project is to deal with those uncertainties.

- Two algorithms interacting each other have been developed, one acting as the Airlines Operation Centre and the other as the Network Manager.

More info at: http://www.onboard-sesar.eu/
DESCRIPTION OF THE PROJECT

Network Manager (NM) - Wx forecast, Unscheduled demand

Capacity/Traffic Load

Air user Ops. Centre (AOC) - Tool to generate the Evaluation scenarios

Schedule

TTA/TTOs - RBTs

Recovery plan
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GLOBAL SYSTEM CONCEPT
GLOBAL SYSTEM CONCEPT

The architecture defined foresees the exchange of information through databases. This approach has several benefits.

- Independent development (AOC and NM) in terms of code and platform.
- Possibility of doing backups easily and run scenarios using stored backup data.
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AIRLINES

OPERATIONS

CENTRE
Objective: find the sequence of flights to be flown by each aircraft that minimizes the total cost and guarantees that all planned flights have been flown once and only once.

Formulation:

Minimise $c^T x$
Subject to: $Ax = b$
$x \leq C$
$c = 1$
$x \in \{0,1\}^n$

Model: Time-Line Network

Description
- Nodes: represent location and time with associated flow.
- Arcs: represent movement between two nodes with associated capacity and cost/profit.
- Aircraft represent the commodities which are routed through the network with every arc.
The Airlines Operations Centre is in charge of the following functionalities:

- Keep or cancel the flight legs on ground
- Change the assignment of aircraft tails to flight legs on ground
- Change the departure time of each flight leg on ground
- Re-time a SBT on ground (e.g. changing the CI or speed profile)
AOC MATHEMATICAL MODEL
ONBOARD NETWORK MANAGER
Allocating Airspace Resources:

Flow Based Models:

**Aggregate** Flights within the optimizer mean only particle **flow rates** are known.
NETWORK MANAGER

Allocating Airspace Resources:

capacity demand

Flow Based Models:

Aggregate Flights within the optimizer mean only particle flow rates are known.

BIG QUESTION:
How do we include uncertainty in this problem?

WHAT’S NEW:
Previously: chance constraints
Now: disturbance feedback
BASE ATFM MODEL

Cells:

Paths are *grouped by destination* and split into a series of *cells* which each represent a sector in the shared flight path. Control actions are represented as binaries:

\[ u^i(k) = \text{no. aircraft held back at cell } i \text{ in time period } k \]
\[ u^{i\rightarrow j}(k) = \text{no. aircraft moving, cell } i \rightarrow j \text{ in time period } k \]
FLOW BASED

**Objective:**
Minimize weighted sum of **Airborne Delay + Ground Delay**

\[
\min \sum_{k \in T} \left( \sum_{s \in S} \sum_{i \in B(s)} c_a u^i(k) + \sum_{a \in A} \sum_{i \in B(a)} c_g u^i(k) \right)
\]

**Capacity Constraints:**

\[
\sum_{i \in B(s)} \left( u^i(k) + \sum_{j \in L_i} u^{i,j}(k) \right) x^i(k) \leq C_s(k)
\]

\[\forall s, k \in T : k > 1\]
FLOW BASED

Objective:
Minimize weighted sum of **Airborne Delay + Ground Delay**

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\]

**Predicted capacity over time**
(\text{DETERMINISTIC})

**BIG DEAL:**
Uncertainty in this Capacity due to Weather
WHY FEEDBACK FOR UNCERTAINTY?

Nominal Plans
- Single plan
- Plan for most likely scenario
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Robust Plans
- Single plan
- Robust to all possible scenarios
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Feedback Plans
- Multiple plans
- Robust to all possible scenarios
- Represented by feedback
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- Represented by feedback

Disturbance Feedback Formulation:
Express the control variables as functions of the disturbance seen:

Control = Baseline Control + Feedback * Disturbance Signal

Action Action Term Signal

• Use this to enable us to react to differing weather capacity scenarios
DISTURBANCE SIGNAL: SCENARIO TREE

1. 

2. 

[Diagram showing a scenario tree with nodes and edges representing different scenarios over time.]
DISTURBANCE SIGNAL: SCENARIO TREE

W’s are the binary **branching points**, so each scenario is represented by a individual set of W’s.

We define associated **capacity reductions** for each scenario, e. These then count towards the sector capacity. i.e. they are appended to this side of the previous capacity equation.

\[
\sum_{i \in B(s)} \left( u^i(k) + \sum_{j \in \mathcal{L}_i} u^{i,j}(k) \right) \leq c_s(k) - q(e, s, k)
\]

\[\forall s, k \in \mathcal{T} : k > 1\]
FEEDBACK REFORMULATION

Control Variables:

\[ u^i(k) = v^i(k) + \sum_{n : tw(n) < k} M^i_n(k) W_n(c) \]

Objectives:

\[
\begin{align*}
\min \epsilon_1 \sum_{k \in T} \left( \sum_{s \in S} \sum_{i \in B(s)} c_{td} v^i(k) + \sum_{a \in A} \sum_{i \in B(a)} c_g v^i(k) \right) \\
+ \epsilon_2 \sum_{w \in W} \sum_{k \in T} \left( \sum_{s \in S} \sum_{i \in B(s)} c_{td} u^i(k) + \sum_{a \in A} \sum_{i \in B(a)} c_g u^i(k) \right)
\end{align*}
\]

\[ \epsilon_2 \ll \epsilon_1 \]

Delay Cost of nominal (disturbance-free) plan

Delay Cost of disturbance recovery plans
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RESULTS
RESULTS: PROBLEM TEST CASE

- **30** flights
- **5** airports, **17** sectors
- Flights between **06:00h** and **16:00h**
- **5**-aircraft capacity limit
- **5**-minute time windows

- **Capacity Reduction Scenarios**
  - **4** storms, one subject to some speed uncertainty
  - Storms reduce capacities to **1 aircraft per 5-minute** time window.
RESULTS: PROBLEM TEST CASE

- **30** flights
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**Capacity Reduction Scenarios**
- **4** storms, one subject to some speed uncertainty
- Storms reduce capacities to **1 aircraft per 5-minute** time window.

**CURRENT SCOPE:**
200 flight problem in less than 2 minutes
TEST CASE RESULTS: INTERACTION

- **Iterative Process:**

  - **ITERATION 1:** NM introduces additional delays to meet capacity restrictions

  - **ITERATION 2:** AOC re-adapts its ideal plan considering NM output

  - **ITERATION 2:** NM suggests new delays to meet capacity restrictions

- **Start:** AOC shares an ideal plan

- **Start:** AOC shares an ideal plan

- Iterative process continues until convergence is reached i.e. AOC plan meets all capacity restrictions.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>No. Sector Capacity Breaches</th>
<th>Ground Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AOC Ideal Plan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c_1$</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>$c_2$</td>
<td>13</td>
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</tr>
<tr>
<td>$c_3$</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>$c_4$</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Solve Time: 4.6 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nominal</strong></td>
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<td></td>
</tr>
<tr>
<td>$c_1$</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>$c_2$</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>$c_3$</td>
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<td>18</td>
</tr>
<tr>
<td>$c_4$</td>
<td>2</td>
<td>18</td>
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<tr>
<td>Solve Time: 4.9 s</td>
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<tr>
<td><strong>Robust</strong></td>
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<tr>
<td>$c_1$</td>
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<td>20</td>
</tr>
<tr>
<td>$c_2$</td>
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<td>20</td>
</tr>
<tr>
<td>$c_3$</td>
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<td>20</td>
</tr>
<tr>
<td>$c_4$</td>
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<td>20</td>
</tr>
<tr>
<td>Solve Time: 14.5 s</td>
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<tr>
<td><strong>Disturbance Feedback</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c_1$</td>
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<td>18</td>
</tr>
<tr>
<td>$c_2$</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>$c_3$</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>$c_4$</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Solve Time: 130.3 s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RESULTS: BENEFITS OF FEEDBACK

<table>
<thead>
<tr>
<th>No. Sector</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>

**Disturbance Feedback solve times now on the order of several seconds:**
- Due to reduced number of control variables in time.

**200 Flight problems now possible**
RESULTS: DISTURBANCE FEEDBACK

Scenario 1

Scenario 4
FURTHER WORK

- Incorporate unscheduled demand.

- Increase the problem size.
  - The main goal is to handle up to several hundred flights in one iteration. Meaning that thousands of flights can be considered during one day.

- Conduct a series of tests in order to demonstrate the benefits of this approach.
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CONCLUSION
CONCLUSION

- The integrated AOC / NM has been presented.

- The benefits of a disturbance feedback approach over a single robust plan have been demonstrated.

- The system is ready to run realistic size problems in a rolling window fashion.

- A testing platform based on databases has been set up between University of Bristol and GMV in order to conduct the testing phase.
Thank you

ONBOARD Team

http://www.onboard-sesar.eu