Coordinated capacity and demand management in a redesigned ATM value chain.
Strategic network capacity planning under demand uncertainty

Prof. Dr. Frank Fichert
Worms University of Applied Sciences
Joint work with:
University of Belgrade (Dr Radosav Jovanović, Nikola Ivanov, Goran Pavlović, Prof. Obrad Babić)
University of Warwick (Dr Arne Strauss, Dr Stefano Starita)

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COCTA Objective

**Incentivize more cost-efficient outcomes!**

In a re-designed ATM value-chain, propose and evaluate coordinated economic measures aiming to pre-emptively reconcile air traffic demand and airspace capacities, by acting on both sides of the inequality.

**Focus:**
- Strategic and pre-tactical phase, i.e. up to and including D-1
- En-route airspace (mindful of airport capacity and terminal airspace constraints)
COCTA process and timeline

**COCTA Process Overview**

- **5 years**: Network Manager (NM) orders nominal **capacity profile** from ANSPs.
- **6 month**: NM orders **capacity** (measured in sector-hours) from ANSPs and starts to offer trajectories to Aircraft Operators (AO).
- **6 month - 1 week**: AO order trajectories, NM can re-order capacities or modify charges (prices non-decreasing with time).
- **1 week**: NM assigns specific trajectories to AO and decides on **Sector Opening Scheme**.

**Key Element of today’s presentation**

Strategic decision on capacity order **under uncertainty**.
Basic COCTA model

Simplified optimization model (Strauss et al. 2016 – SID website):

- Centralized decision making regarding ANSPs’ capacities and AOs’ routes (trajectories) reduces overall costs of ATC provision

Decisions made by Network manager:

- Order (maximum) capacity from five ANSPs (Q, R, S, T, U)
- Decide on sector opening scheme and allocate flights within network (including displacement in time (delays) and space (re-routing))
Extended COCTA model

Key assumptions

The majority of flights are known in advance (80%), up to 20% of flights appear at short notice (e.g. charter, all cargo, business aviation, military).

Network manager has to decide on maximum capacity provision six months in advance, it may use less capacity at the day of operation (leading to some cost savings).

Key question for this paper

How should the decision on maximum capacity provision be made – and what are the potential consequences of that decision?
Case study – Numerical values

Two hour period – with 30 minutes minimum duration of sector opening (i.e. R, S, T, U: 2 - 4 sector hours / Q: 2 - 6 sector hours)

120 ‘known’ flights, up to 30 ‘random’ flights (random: no. of flights, aircraft type, O&D, time)

Assumptions for sector opening costs (different between ANSPs) and AO’s displacement costs (depending on aircraft type – we use three types)

Maximum capacity and no. of flights defined for five minutes interval

![Graph showing number of flights over time](image-url)

*Figure 2. One traffic sample with 150 flights (30 uncertain flights)*
Case study – model structure

1. **Scenario identification (SI)**
   Run a large number of simulations with random flights and **identify specific network optimum**.

2. **Scenario test (ST)**
   **Test result** of step 1 by running again a large number of simulations, this time with maximum capacity based on result of step 1.
### Case study – SI results

**TABLE I.**

**CAPACITY ORDERING SCENARIOS TESTED**  
*(ALL VALUES IN SECTOR HOURS)*

<table>
<thead>
<tr>
<th>Scenario outcome</th>
<th>ANSP</th>
<th>Total capacity budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>2.5</td>
<td>11.5</td>
</tr>
<tr>
<td>MIN2</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>MIN3</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>FREQ</td>
<td>2.5</td>
<td>12.5</td>
</tr>
<tr>
<td>MAX2</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>MAX3</td>
<td>3</td>
<td>13.5</td>
</tr>
<tr>
<td>MAX</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>MAX-PLUS</td>
<td>3.5</td>
<td>15</td>
</tr>
</tbody>
</table>

Except MAX-PLUS, all scenarios were optimal at least in one model run.

FREQ was the optimum configuration in the largest number of simulations.

MAX-PLUS might be the result of delay-averse and non-coordinated capacity planning.
Case study – ST results

FREQ as total cost minimizing scenario (on average)
Trade-off between capacity cost and displacement cost
Case study – ST results

**Table II: Network Performance Indicators under Different Capacity-Ordering Scenarios Tested**

<table>
<thead>
<tr>
<th>Scenario Outcome</th>
<th>Capacity budget (sector-hours)</th>
<th>Fixed capacity cost in EUR (average)</th>
<th>Variable capacity cost in EUR (average)</th>
<th>Average displacement cost in EUR [st. dev.]</th>
<th>Total cost in EUR (average)</th>
<th>Average number of displaced flights [st. dev.]</th>
<th>Total delay (minutes)</th>
<th>Average delay (minutes) per delayed flight (average)</th>
<th>Number of flights delayed ≥20min (average)</th>
<th>Relative incidence (% of all) sector-periods with utilisation ≥85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>11.5</td>
<td>6,080</td>
<td>15,990</td>
<td>12,583 [3,203]</td>
<td>34,653</td>
<td>63.5 [6.6]</td>
<td>526</td>
<td>9.5</td>
<td>6.0</td>
<td>32.4</td>
</tr>
<tr>
<td>MIN2</td>
<td>12</td>
<td>6,385</td>
<td>16,782</td>
<td>11487 [3,442]</td>
<td>34,654</td>
<td>60.3 [7.2]</td>
<td>507</td>
<td>9.3</td>
<td>4.6</td>
<td>31.1</td>
</tr>
<tr>
<td>MIN3</td>
<td>12</td>
<td>6,330</td>
<td>16,624</td>
<td>9,905 [1,727]</td>
<td>32,859</td>
<td>63.9 [7.4]</td>
<td>372</td>
<td>8.1</td>
<td>2.1</td>
<td>28.1</td>
</tr>
<tr>
<td>FREQ</td>
<td>12.5</td>
<td>6,635</td>
<td>17,541</td>
<td>8,280 [1,591]</td>
<td>32,456</td>
<td>56.4 [7.3]</td>
<td>336</td>
<td>7.8</td>
<td>1.3</td>
<td>27.9</td>
</tr>
<tr>
<td>MAX2</td>
<td>13</td>
<td>6,885</td>
<td>17,769</td>
<td>7,954 [1,293]</td>
<td>32,608</td>
<td>55.6 [6.6]</td>
<td>314</td>
<td>7.6</td>
<td>1.1</td>
<td>27.4</td>
</tr>
<tr>
<td>MAX3</td>
<td>13.5</td>
<td>7,135</td>
<td>18,886</td>
<td>7,771 [1,074]</td>
<td>32,792</td>
<td>54.9 [6.0]</td>
<td>301</td>
<td>7.5</td>
<td>1.0</td>
<td>27.6</td>
</tr>
<tr>
<td>MAX</td>
<td>14</td>
<td>7,385</td>
<td>17,891</td>
<td>7,759 [1,057]</td>
<td>33,036</td>
<td>55.0 [6.0]</td>
<td>300</td>
<td>7.4</td>
<td>1.0</td>
<td>27.6</td>
</tr>
<tr>
<td>MAX-PLUS</td>
<td>15</td>
<td>7,940</td>
<td>17,935</td>
<td>7,713 [1,016]</td>
<td>33,588</td>
<td>54.7 [5.8]</td>
<td>298</td>
<td>7.4</td>
<td>1.0</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Indicators: Total cost, number of large delays (‘fairness’), ‘robustness’ (measured by periods with high utilization)
Case study – Key observations

1. **Small effect of MAX-PLUS on displacement**
   Avoidance of displacement costs smaller than additional cost of capacity provision.

2. **Effect of aircraft size**
   Due to cost minimization objective, large aircraft (with higher displacement costs) get less displacements (also positive for environmental indicator).

3. **Large effects of (some) small changes**
   Comparison between MIN2 and MIN3 shows relatively large effect of shifting 0.5 sector hours from one ANSP to another.
Conclusions and outlook

1. Suitable model for capacity decisions under uncertainty
   Developed for COCTA model, but also applicable for non-coordinated capacity decisions.

2. Positive effect of coordination (esp. MAX-PLUS scenario)

3. Reduction of uncertainty and less peaky (or ‘flatter’) traffic distribution over time might increase efficiency

4. Options for future modeling
   - Use of actual traffic data
     (also as guard rails for random traffic)
   - Multi criteria objectives instead of cost minimization
   - Add incentives within demand management
Coordinated capacity and demand management in a redesigned ATM value chain

Thank you very much for your attention!