Interactions between Operations and Planning in Air Traffic Control

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Different Layers of the Air Traffic Management

Different layers corresponding to different time horizons:

1. Airspace management filter:
   - define the structure of the route network
   - define navigation rules
   - divide the airspace between sectors with given capacities

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2. Air Traffic Flow Management (ATFM):
   - file flight plans a few hours before planned take-off
   - regulate traffic to enforce sector capacities with ground-holding (CASA)
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3. Air Traffic Control (ATC) where controllers:
   ▶ monitor sectors;
   ▶ ensure safe transitions between sectors;
   ▶ maintain separation between aircraft at all times.

Figure 1: Vertical and horizontal separation
Present and future: what is at stake?

1. Present situation:
   - airspace congested in Europe
   - costly delays crucial to companies
   - few conflicts to solve for controllers
Present and future: what is at stake?

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2. Questions needing answers for the future:
   - what will future traffic look like?
   - how will regulations adapt to this future traffic?
   - what economic outcomes can be expected?
   - how to be better prepared?
Our contributions

Based on an air traffic simulator we:

- simulate future French traffic up to 2035
- design different regulation scenarios
- compute ground-holding costs and ATC costs
- perform a traffic and cost analysis
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The whole picture

Figure 2: Experimental design
Traffic increase

Procedure parametrized by a multiplying factor $f$ (i.e. 40%):

- go from $n$ flights to $n_+ = n(1 + f)$ flights:
  - 1. choose random flights to be duplicated
  - 2. apply a small perturbation on departure time

- same random seed used: consistent increase

- maintain a similar temporal distribution of flights
Ground-holding regulation: CASA Algorithm

Computer Assisted Slot Allocation (CASA)

- Allocates slots for take-off
- Greedy heuristic (FIFO fashion)
- one delay value for each overflown regulated zone
- assigned delay: maximum delay over all overflown regulated zones
Traffic simulation and conflict resolution

Traffic simulator: Complete Air Traffic Simulator (CATS)
- time-discretized execution model
- aircraft specifications and performances extracted from BADA tables
- detailed outputs: traffic statistics, sector occupancy, conflicts data
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Air conflict resolution used:
- genetic algorithm from Durand(1996)[4]
- embedded in CATS
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Traffic predictions

Data extracted from EUROCONTROL forecasts[2, 1]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Global Growth</th>
<th>Regulated Growth</th>
<th>Happy Localism</th>
<th>Fragmented World</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-2019</td>
<td>3.4%</td>
<td>2.3%</td>
<td>2.3%</td>
<td>0.9%</td>
</tr>
<tr>
<td>2019-2020</td>
<td>3.7%</td>
<td>2.2%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>2021-2025</td>
<td>2.5%</td>
<td>1.9%</td>
<td>1.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>2026-2030</td>
<td>2.2%</td>
<td>1.5%</td>
<td>1.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>2031-2035</td>
<td>1.9%</td>
<td>1.2%</td>
<td>1.1%</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

**Table 1:** Summary of flight forecast for Europe until 2035

<table>
<thead>
<tr>
<th>Year</th>
<th>2014</th>
<th>2017</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td>+5%</td>
<td>+12%</td>
<td>+20%</td>
<td>+32%</td>
<td>+42%</td>
<td>+50%</td>
</tr>
</tbody>
</table>

**Table 2:** Traffic predictions with Regulated Growth
Airspace Capacity

Nominal sector capacities for France were used:

- different from actual regulation
- remains a valid indicator

Two scenarios of simulations:

- $S_1$: the actual regulation is applied with unchanged capacities
- $S_2$: no ground regulation is applied
Airspace Capacity

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Extreme situations to challenge both:
- ground regulation: assigning take-off slots under high demand ($S_1$)
- ATC regulation: conflict resolution with numerous aircraft ($S_2$)
Choice of historical data

Week of French traffic from 2012:

- high volumes, especially on 6/8
- consistent differences between computed delays and actual delays

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of flights</th>
<th>Computed delays (min)</th>
<th>CFMU delays (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/6</td>
<td>8656</td>
<td>1835</td>
<td>4503</td>
</tr>
<tr>
<td>6/7</td>
<td>8723</td>
<td>1875</td>
<td>8845</td>
</tr>
<tr>
<td>6/8</td>
<td>9053</td>
<td>16086</td>
<td>15505</td>
</tr>
<tr>
<td>6/9</td>
<td>8469</td>
<td>5708</td>
<td>13215</td>
</tr>
<tr>
<td>6/10</td>
<td>8786</td>
<td>11075</td>
<td>10924</td>
</tr>
<tr>
<td>6/11</td>
<td>8817</td>
<td>5507</td>
<td>11449</td>
</tr>
<tr>
<td>6/12</td>
<td>8618</td>
<td>4739</td>
<td>8006</td>
</tr>
<tr>
<td>Average</td>
<td>8731.7</td>
<td>6689.3</td>
<td>10349.5</td>
</tr>
</tbody>
</table>

Table 3: Traffic statistics from 2012/6/6 to 2012/6/12
Delay costs

Delay costs need to account for:

- passenger costs
- crew costs
- maintenance costs
- subsequential delays
Delay costs

Delay costs need to account for:
- passenger costs
- crew costs
- maintenance costs
- subsequential delays

Data used: model designed by EUROCONTROL and Westminster University[3]
- cost function of delay magnitude and type of aircraft involved
- data stored in tables

<table>
<thead>
<tr>
<th>Delays (min)</th>
<th>15</th>
<th>60</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>B744</td>
<td>1230</td>
<td>20760</td>
<td>120940</td>
<td>213950</td>
</tr>
<tr>
<td>A320</td>
<td>410</td>
<td>6800</td>
<td>35280</td>
<td>63530</td>
</tr>
</tbody>
</table>

Table 4: Tactical costs (euros, total) of ground holding delay
Maneuvers costs

Three types of maneuvers issued:

- speed changes
- heading changes
- ascent interruption or descent anticipation
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- heading changes
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Costs computed as extra fuel cost:
- define nominal speed with BADA performances
- compute fuel consumption on original flight plan at nominal speed $C_{\text{nom}}$
- compute fuel consumption during the maneuver $C_{\text{man}}$
- the extra cost is the difference $C_{\text{nom}} - C_{\text{man}}$
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Simulations without conflict resolution (1/2)

Figure 3: Entering flow per hour for different traffic volumes on KR control sector

(a) +0%  
(b) +32%  
(c) +42%  
(d) +50%
Impact of ground-holding regulation

Figure 4: Comparison of the number of conflicts observed with and without CASA
Simulations without conflict resolution (2/2)

Impact of ground-holding regulation:

- prevents flight aggregation into peaks ↔ eases controller’s task
- smoothes the flow over the day
- reduces the number of conflicts for heavily loaded sectors
Ground-holding regulation costs

Figure 5: Cost of ground-holding regulation (in euros)
ATC costs

Figure 6: Deconfliction costs and maneuvers per hour
 Costs Analysis

1. Regarding ground-holding regulation costs:
   ▶ grow exponentially with traffic volume
   ▶ due to larger peak periods, hence larger delays
   ▶ millions of euros could be saved by removing capacities

2. Regarding ATC deconfliction costs:
   ▶ remain small compared to ground-holding costs
   ▶ removing capacities increase resolution costs by 15%
   ▶ removing capacities dramatically increases workload
   ▶ conflict situations more and more difficult to solve

3. How to take advantage of this information?
   ▶ cf. SESAR project [5]
   ▶ higher degree of automation
   ▶ design a new regulation
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Scientific contributions

- Simulations on future traffic extrapolated from real-life data
  - increased traffic based on detailed forecasts
  - insight into future traffic conflict situations

- Study of interactions between ground-holding regulation and ATC:
  - Millions of euros can be saved daily by removing sector capacities
  - Additional ATC effort increases cost by 15%
  - Controllers’ workload increases dramatically

- Have an insight into future solutions:
  - design a regulation better adapted to dense traffic
  - need of highly automated tools to decrease workload
Perspectives

Future work will focus on:

1. follow more detailed forecasts

2. introduce an hybrid scenario $S_3$:
   - determine new capacities
   - control ground holding regulation costs
   - control increase in controller’s workload

3. perform the same study on direct routes
References I

- **Eurocontrol long-term forecast: IFR flight movements 2013-2035.**

- **Eurocontrol medium-term forecast: IFR flight movements 2013-2019.**

- **A. J. Cook and G. Tanner.**
  European airline delay cost reference values. 2011.

- **N. Durand, J. Alliot, and J. Noailles.**
  Automatic aircraft conflict resolution using genetic algorithms.

- **SESAR Joint Undertaking.**
  European ATM master plan, edition 2.