Optimisation and Prioritisation of Flows of Air Traffic through an ATM Network

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Overview

● The ATM Network in Europe

● To enable Optimizing and Prioritizing ATFM by OPT-ATFM:
  ● Local context in space and time
  ● How to apply enhanced ATFM

● Model-based experiment:
  ● Scenario
  ● Slot selection, using prioritization
  ● Prioritization applied on 6 airport flows (5 disrupted)
  ● Results

● Conclusions
Aim to develop prototype implementation of enhanced ATFM algorithm

- **Problems in the European ATM Network:**
  - Systematic overload and congestion of small number of major airports
  - Airports with unbalanced operational conditions, e.g. by weather
  - Some airports suffering access restriction by lack of capacity of TMAs, e.g. London area
  - Some ATS routes are critical due to En-route constraints, e.g. in the Core Area

- **EC statement:**
  - "...the use of transparent and efficient rules will provide a flexible and timely management of air traffic flows at European level and will optimize the use of air routes."

- **Objective of this research:**
  - To demonstrate benefits by regulating departure flows with enhanced ATFM algorithm
  - Aim to apply ATFM with maximum throughput, best achievable efficiency and minimum impact on flight performance
The ATM Network and the Bottlenecks

Network defined by:
- non-optimal number of sectors
- non-optimal distribution of air traffic

Problems:
- Specific sector nodes with overload problems
- Very thick and very thin traffic flows
- Airports nodes very small, very large and sometimes very congested

Conclusion:
- Network is super critical
- Solving bottlenecks to make Network robust
- More robust network by aggregation
Enhanced ATFM in adherence to SESAR

• ATFM today:
  • ICAO flightplans, possibly updated
  • Assign overloaded nodes to be regulated
  • FC-FS: Assign departure slots on overloads by first arrival at the overloaded node (sector)

• Options for Optimization and Prioritization:
  • Economic value prevails over FC-FS principle
  • 4D RBTs, up-to-date by SWIM (SESAR)
  • Apply optimization towards minimized imposed delays
  • Impose pre-departure delay, whilst being able to assess impact on other flight operations
  • Apply optimization towards the economic value of flight by prioritization

• Alternative solutions:
  • MILP and find optimum against minimizing cost-function
  • Use Petri-Nets and select a local context in space and time
Optimising and Prioritising ATFM in Local context of space and time

Proposed solution for improvement:

Weighted minimisation of imposed delays over 1 sector during 1 hour

Imposed pre-departure delays
Demand and Capacity Balancing (DCB)
Solution Strategy

- **Full ATM network, including Airports**
  - Sensitive for unbalance, congestion and overload, but
  - More accurate and stable load, and thus higher declared capacity

- **Local context in space (node) and time (1 hour):**
  - FC-FS $\Rightarrow$ Pre-departure delay for first flight to hit overloaded node
  - Select the best one: **natural trade-off within local context**
  - Option 1: to select within node with minimized penalties
  - Option 2: to look at impact of pre-departure delay on other nodes (before and behind overloaded node)
  - Option 3: to give priority to congested flows
  - Option 4: to give priority to flights on economic value

- **Success criteria:**
  - **DCB model (OPT-ATFM):** Evaluate minimum pre-departure delay and minimum “waiting time”
  - **Operational validation by Fast Time Simulation:** Evaluate minimum flight delay, flight efficiency, workload
ATM: DCB Network and Flight operations Network

DCB Network:
- Airport node capacity: Sustainable/Max. capacity in mov.
- Sector node capacity: Declared capacity
- Air traffic demand: Demand per node per hour

Flight operations:
- Airport load: departure/arrival throughput
- Sector load: workload and complexity
- Air traffic operations: actual departures
Model-based Experiment on Kernel Network Scenario with 15 main (hub) airports

Kernel Network defined by a wider area of Europe around the Core Area.

Capacity:
- 15 main (hub) airports
- 514 other airports
- 736 sectors

Demand:
- 24,600 flights
OPT-ATFM: slot selection in congested node with minimized imposed delay

Example in busy Brussels sector, start of the day, optimized ATFM:
- In-flight (lila), in-flight via out-node (orange),
- Flow managed (blue), Flow-managed with penalty in other sector (red)
Experiment to optimize throughput with 5 disrupted /6 prioritized airports

- **Sensitivity analysis of ATM Network throughput:**
  - Kernel Network, 24,600 flights through Core Area

- **Three runs (OPT-ATFM):**
  - Normal scenario, calculate imposed pre-departure delay
  - Disrupted scenario, 5 airports disrupted (assumed lower capacity: EHAM, EDDF, EDDM, EGKK, LFPG), calculate imposed pre-departure delay
  - Disrupted scenario:
    - 5 airports disrupted (capacity -20% to -30%)
    - 6 airports prioritized (5 disrupted + EGLL added)
    - Calculate imposed pre-departure delay

- **Compare:**
  - Distribution of “Waiting time” over the day
  - Geographical distribution of imposed pre-departure delay
  - Comparing imposed pre-departure delays of large airports
Hourly distribution “Waiting time” and Hourly distribution imposed pre-departure delay

- Example of applying OPT-ATFM with prioritisation:
  1. Measure “Waiting time” over Kernel Network (5 airports disrupted (Blue line left))
  2. Calculate pre-departure delays for 6-airports prioritised scenario (blue line right)
  3. Measure “Waiting time” per node accepting imposed delays (red line left)
Kernel Network:
- Apply OPT-ATFM

ATFM, no prioritisation:
- #flights “waiting” time: ~4,800
- Total “waiting” time: ~12,000 hrs.
- #flights imposed delay: ~5,300
- Av. imposed delay: 34,9 min.
- At main airports: 53,5 min.

Conclusion: Waiting time resulting from reduction in capacity at main airports solved mainly by assigning pre-departure delays to these airports.
5-airports disrupted scenario
Apply OPT-ATFM with prioritisation (6 airports)

Kernel Network:
- Apply OPT-ATFM (+ prio)

ATFM, with prioritisation:
- #flights “waiting” time:
  - ~6,000
- Total “waiting” time:
  - ~11,200 hrs.
- #flights imposed delay:
  - ~6,400
- Av. imposed delay:
  - 31,7 min.
- At main airports:
  - 29,9 min.

Conclusion: Waiting time resulting from reduction in capacity at main airports distributed and largely assigned to less congested small airports.
Compare OPT-ATFM without and with prioritisation (per airport)

Imposed pre-departure delay at 20 most affected airports compared to PrioCase after OPT-ATFCM (hrs)

Blue: Reference case, no excessive delays
Red: No prioritisation, 5-airports disrupted, 5 airports heavy delayed
Green: With prioritisation, 6 airports enhanced performance, other airports decreased performance
Some conclusions

- **Feasibility evaluated:**
  - Analysis of ATM network as a network, not by assessment of operational performance
  - Assessment of DCB, using 4D trajectory predictions
  - Flow management within local context of space and time
  - And .... with *optimisation* and *prioritisation*

- **Transparency:**
  - Penalties/benefits per node per priority class

- **Experimental results (of first experiment):**
  - Comparing a 5-airports disrupted scenario with and without prioritisation to/from congested destinations:
    - Decrease of total amount of delay
    - Decrease of average delay
    - Strong decrease of delay at main airports (-40%)

- All together a more efficient re-distribution of imposed delays
Thank you

Recent reports:

Demand and Capacity Balancing (DCB) Solution Strategy

- **Balancing Demand and Capacity (static picture)**
  - Capacity per sector:
    - Over-dimensioned network: Aggregation
  - Capacity per Airport:
    - Peak capacity, operational achievable throughput
    - Varying demand/capacity, solved e.g. by hourly capacity over the day
    - No differentiation between departure and arrival flows
  - Demand (converging and layered planning):
    - 4D Reference Business Trajectories (RBTs) and SWIM

- **DCB (dynamic picture):**
  - Flows through network (unconstrained) → Bottlenecks
  - Flows through network (constrained) → Throughput and “waiting Time”
  - Pre-departure imposed delays → to suppress waiting time
  - Question: How to optimize “Pre-departure delay” versus “waiting time”?
Network Analysis Model (NAM)

Bottleneck analysis

Throughput analysis through ATM networks:

- Applicable to sub-networks
- **Airports** and **Sectors** treated as identical nodes in the network
- Used:
  - To detect **hot-spots** at airspace and airport level
  - To analyse **balance** in the network
  - To optimise towards minimal “waiting periods”
Iteration of ATFM: Reduced waiting time by Imposed pre-departure delays

- Conclusion:
  Under nominal conditions (no disruption and no connectivity) fairly equalised balance between waiting periods at sectors and at airports (40%-60%).
Experiment, comparing FC-FS ATFM with OPT-ATFM (PRIIO)

- **Conduct of experiment:**
  1. Measure “Waiting time” per node
  2. Calculate pre-departure delays to mitigate “waiting time”
  3. Measure “Waiting time” per node accepting imposed delays

Example (EHAM) of disruption by (30%) reduction of capacity
## Compare ATFM without and with prioritisation

### Throughput analysis by measuring “Waiting time”

<table>
<thead>
<tr>
<th></th>
<th>ATFM FC-FS</th>
<th>PrioCase</th>
<th>Percent.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number of flights</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of flights with a waiting time in period</td>
<td>4774</td>
<td>5998</td>
<td>26%</td>
</tr>
<tr>
<td><strong>Total waiting time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total waiting time in period (hrs)</td>
<td>12003</td>
<td>11246</td>
<td>-6%</td>
</tr>
</tbody>
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### Calculated imposed pre-departure constraints

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<td><strong>Total number of flights</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of flights with a pre-departure delay in period at airports</td>
<td>5324</td>
<td>6387</td>
<td>20%</td>
</tr>
<tr>
<td>Number of flights with a pre-departure delay in period at main airports</td>
<td>3448</td>
<td>3368</td>
<td>-2%</td>
</tr>
</tbody>
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### Total pre-departure delay after each run

<table>
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<th>Percent.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total pre-departure delay in period at airports (hrs)</strong></td>
<td>12199</td>
<td>11076</td>
<td>-9%</td>
</tr>
<tr>
<td>Pre-departure delay in period at main airports (hrs)</td>
<td>10010</td>
<td>5589</td>
<td>-44%</td>
</tr>
</tbody>
</table>

### Average per flight after each run

<table>
<thead>
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<th>ATFM FC-FS</th>
<th>PrioCase</th>
<th>Percent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-departure delay in period (min)</td>
<td>34.9</td>
<td>31.7</td>
<td>-9%</td>
</tr>
<tr>
<td>Pre-departure in period at main airports (min)</td>
<td>53.5</td>
<td>29.9</td>
<td>-44%</td>
</tr>
<tr>
<td>Pre-departure in period at remaining airports (min)</td>
<td>13.7</td>
<td>34.4</td>
<td>151%</td>
</tr>
</tbody>
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