DMAN-SMAN-AMAN Optimisation at Milano Linate Airport

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Introduction

Every single study predicts an impressive air traffic growth over the next decade(s)

<table>
<thead>
<tr>
<th>Year (SESAR-2020 horizon)</th>
<th>Traffic increment wrt 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023</td>
<td>+14%</td>
</tr>
<tr>
<td>2035</td>
<td>+40%</td>
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</tbody>
</table>

In the medium-long term it will be impossible to accommodate the expected flights with present infrastructures and services.

**SESAR Solutions:** Departure MANager (DMAN), Arrival MANager (AMAN), Surface MANager (SMAN), Airport – Collaborative Decision Making (A-CDM).
Departure MANager (DMAN)

Present procedure: First Come First Served (FCFS)
• controllers authorize A/C to start up and taxi to the runway as soon as ground handling operations are concluded;
• traffic flow is not smooth: queues, delays, uncertainty, unnecessary fuel burning and noise emissions.

DMAN procedure:
• determines departure sequence at the runway computing the Target Take-Off Time (TTOT);
• determines pre-departure sequence computing the Target Start up Approval Time (TSAT), starting from the runway and going back to the parking stand.

DMAN considers:
• scheduled departure times;
• EU departure slots constraints;
• local airport factors;
• wake vortex and instrumental procedures separations.

DMAN Advantages:
+ traffic awareness;
+ environmental sustainability;
+ safety;
- cost.

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Arrival MANager (AMAN)

Present procedure: First Come First Served (FCFS)
• aircraft are separated and sequenced following their entry time in the TerMinal Control Area (TMA);
• if runway capacity is saturated, aircraft are obliged to hold in air before obtaining landing clearance.

AMAN procedure:
• determines the optimum approach/landing sequence computing the Target Landing Times (TLDT);

AMAN Considers:
• scheduled arrival times;
• airport factors;
• wake vortex and ATC separations.

AMAN advantages:
+ traffic flow smoothness;
+ traffic awareness;
+ environmental sustainability.
**Surface MANager (SMAN) and A-CDM**

**SMAN** is an ATM tool that
- determines the optimal **taxi route** and **ground scheduling**;
- optimises the resource usage (e.g. de-icing facilities);
- + efficiency, + traffic awareness, + safety.

**Airport – Collaborative Decision Making (A-CDM)** is an ATM tool that
- is based on **information sharing** among airport **stakeholders** and on milestone approach.
- allows each airport player to optimise its decisions in **collaboration** with all others.

Integration between the DMAN, SMAN, AMAN, and A-CDM is fundamental for the global optimization of the airport system.
Description of the work

- Objective: design an optimisation algorithm to be applied at Milano Linate airport.
- Co-operation: ENAV Air Traffic Controller and SEA personnel.

Specific objectives, constraints and local procedures.

- Method: heuristic decomposition for solving integrated problem DMAN+SMAN+AMAN:
  - Step 1: ground routing problem (SMAN);
  - Step 2: runway scheduling problem (DMAN+AMAN);
  - Step 3: ground scheduling problem (SMAN).

  ➢ Airport traffic flow optimisation at **global** level.
  ➢ Solution is **sub-optimal** but still gives good results.
  ➢ Very **low** computational time (high dynamicity).

- Validation: comparison optimal data with real data of two case study days.
Milano Linate airport

- In Italian airport panorama (2016):
  - 3\textsuperscript{rd} for aircraft movements;
  - 4\textsuperscript{th} for passenger traffic;
  - 8\textsuperscript{th} port for cargo traffic;
- general, business and commercial aviation;
- **single main taxiway**: bottlenecks could be eliminated using an optimization algorithm for sequencing aircraft.
- **single runway**: mixed mode (take-off and landing) is challenging for the algorithm.
**Step 1: ground routing problem (SMAN)**

Objective: compute a **feasible route** for each aeroplane, minimizing **taxi time** and trying to **exploit all airport resources**.

Constraints:
- assigned parking positions (by airport operator);
- airport topology (modelled with an oriented graph);
- tabulated taxi times (from ACDM platform).

Modelling: Non Linear Programming (NLP) problem.

\[
\min \sum_{f \in F} \sum_{a \in A} u_f^a \cdot \left( l_f^a + \frac{0.1}{\text{card}(F)} \sum_{f \in F} u_f^a \right)
\]

Binary variable: if equal to 1, the arc belongs to the optimal path.

Taxi time of arc \( a \).

Taxi time cost due to arc usage.
For each parking zone $N_i$ and $W_i$, the expected inbound (EXIT) and outbound (EXOT) taxi time is taken from A-CDM. EXIT and EXOT have been divided between the arcs of the airport graph and used to compute route taxi time.
Step 1: ground routing problem (SMAN)
Step 2: runway scheduling problem (DMAN+AMAN)

Objective: find an **optimal scheduling at the runway** for arrivals (**TLDT**) and departures (**TTOT**), minimizing deviation from desired arrival and departure times.

Constraints:
- tolerance windows (with respect to desired times)
- wake vortex separations (RECAT-EU);
- minimal RADAR distances (for arrivals) and SID procedures (for departures);
- departures with CTOT assigned must depart; the others can be dropped.
- arrivals must always land.

Modelling: Integer Linear Programming (ILP) problem.
Step 2: runway scheduling problem (DMAN+AMAN)

Binary variable: if equal to 1, the departure is **dropped** (can't depart within the DTW)

Binary variable: when equal to 1, indicates optimal TTOT and TLDT.

\[
\min \sum_{d \in D} w_d \cdot y_d + \sum_{f \in F, t \in H_f} c_{ft} \cdot \chi_{ft}
\]

- Drop cost.
- Deviation cost.
Step 3: ground scheduling problem (SMAN)

Objective: to compute a **conflict-free schedule** for each flight, minimizing the time the aircraft spend between the parking position and the runway with engines on, and vice-versa.

→ Compute **TSAT** and **TIBT** (Target In-Block Time).

**Constraints:**
- assign a schedule time to arcs and nodes of shortest paths computed at Step 1;
- satisfy the order of arrivals and departures on the runway established at Step 2;
- satisfy all precedence and separation constraints (job-shop scheduling problem).

**Modelling:** Mixed Integer Linear Programming (MILP) problem

\[
\min \sum_{l \in L} (t_{l}^{g_{in}(l)} - t_{l}^{RWY}) + \sum_{d \in D} (t_{d}^{RWY} - t_{d}^{g_{out}(d)})
\]

| TIBT | TLDT | TTOT | TSAT |
Global algorithm flow

- Current: SOBT - 40'
  SIBT - 40'
- Dropped: shifted of 10'
- Scheduled: TSAT - 15'
- On-final: TLDT - 15'
- Taken-off: TTOT + 10'
- On-blocks: TIBT + 10'

Update current flights

Update time

A-CDM

Solve Step 1

Flight path

Solve Step 2

Taxi time

Solve Step 3

Flight is scheduled or on-final

Fix path, TSAT & TTOT, TIBT & TLDT

New ETOT

TTOT & TLDT

NO

YES

YES

NO

Compare data: Optimal vs FCFS

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Differences from baseline formulation

Present paper work is inspired by Kjenstad et Al. studies (2016):
• Heuristic decomposition of the integrated problem DMAN+SMAN+AMAN.
• Applied to Hamburg (two runways) and Arlanda airports (three runways).

Major differences and original contributions:
• Linate context is pretty different (single runway and single main taxiway);
• Step 1: based on "line graph model" → Used simplest "maximum flow model";
• Step 1: not guarantee of full resources exploitation → Added term in obj. function;
• Step 2: flights with CTOT assigned can be dropped → Forced to depart;
• Step 2: no re-scheduling of dropped flights → Added re-iteration;
• General: not fixing optimal values → Changed.
Description of the two case-study days

8th November 2016 (Tuesday):

- **no ice or snow** conditions;
- **no traffic congestion** problems;
- total flights: **314** (almost 50% departures and 50% arrivals);
- 34 general and business aviation flights;
- 56% of flights operated by **Alitalia** (A319, A320, E170, E190).

15th February 2017 (Wednesday):

- **ice condition** (9 aircraft underwent de-icing procedures);
- **no traffic congestion** problems;
- total flights: 328 (almost 50% departures and 50% arrivals);
- total flights analysed: **328-9 = 319**;
- 37 private flights (general and business aviation);
- 53% of flights operated by **Alitalia** (A319, A320, E170, E190).
### Results analysis

<table>
<thead>
<tr>
<th>Day</th>
<th>Type</th>
<th>Time Deviation</th>
<th>Taxi time</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/11/2016</td>
<td>Arrivals</td>
<td>-26% (-30&quot;)</td>
<td>-4% (-10&quot;)</td>
<td>-4% (-300 kg)</td>
</tr>
<tr>
<td></td>
<td>Departures</td>
<td>-0% (/)</td>
<td>-10% (-1' 8&quot;)</td>
<td>-7% (-1.6 ton)</td>
</tr>
<tr>
<td></td>
<td>All flights</td>
<td>-11% (-30&quot;)</td>
<td>-8% (-1' 18&quot;)</td>
<td>-6% (-2 ton)</td>
</tr>
<tr>
<td>15/2/2017</td>
<td>Arrivals</td>
<td>-37% (-37&quot;)</td>
<td>-9% (-36&quot;)</td>
<td>-23% (-1.8 ton)</td>
</tr>
<tr>
<td></td>
<td>Departures</td>
<td>-13% (-36&quot;)</td>
<td>-18% (-2')</td>
<td>-16% (-3.9 ton)</td>
</tr>
<tr>
<td></td>
<td>All flights</td>
<td>-23% (-1' 13&quot;)</td>
<td>-16% (-2' 36&quot;)</td>
<td>-18% (-5.6 ton)</td>
</tr>
</tbody>
</table>

- The algorithm works, in the worst case, as well as Air Traffic Controllers: **more punctuality**.
- Reduction in taxi time yields **less noise, reduced fuel consumption, increased smoothness** and **safety**.
- Reduction in fuel consumption guarantees **lower CO\textsubscript{2}** emission (approx. 13 football fields of forest) and **savings** (approx. 4 k€ in the two days; 2 k€ only by Alitalia).
- Heuristic decomposition guarantees low computational time (< 0.1s per Step), so **high dynamicity**.
+65% of flights take-off without delay or advance.
+40% of flights land without delay or advance.
Outbound Taxi Time Difference for both days

Time saving for optimal case

Number of flights vs. Outbound Taxi Time Difference (min)
Conclusions and future developments

- Following EU directives and using specific tools of the Operational Research, the designed algorithm showed that it is possible to improve Air Traffic Management at Linate airport with an integrated approach DMAN+SMAN+AMAN.

- The comparison of computational results with what actually happened in two case-study days showed that the algorithm can potentially help airport stakeholders in reducing mean time deviation, taxi time and fuel consumption.

- Further analysis are needed, comparing performance with additional days that include different operative conditions, and possibly testing the algorithm in a real-time environment.

- Future developments may comprise:
  - dynamic calculation of the delay along the taxiways;
  - implementation of the "De-icing management tool";
  - implement some algorithm for help ATC to respect computed TLDT;
  - apply the algorithm to other airports (e.g. Milano Malpensa).
Thank you for your attention
