Capacity-Driven Automatic Design of Dynamic Aircraft Arrival Routes

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Overview

✓ **ODESTA project**: optimal design for TMA
✓ **LiU-LFV** joint project funded by Vinnova (Sweden)
✓ **Recap**: optimal Stars (static), sectors, simultaneous design—*Strategic planning*
✓ **New**: time-separated demand-weighter *arrival routes (dynamic)—Pre-tactical planning*
  - problem description
  - constraints and objectives
  - experimental study: Arlanda Airport
✓ **Future**: moving objects avoidance, robust against weather uncertainties
ODESTA project: TMA optimization

✓ Recap:
✓ Automated optimal STARs (static)
✓ Grid-based approach
✓ MIP formulation (solved using GUROBI, CPLEX)
✓ Experimental Study: Arlanda Airport
Recap: optimal STARs - Problem description

**Given**

✓ location and direction of the airport runway
✓ locations of the entry points to the TMA

**Output**

Optimal arrival tree that merges traffic from the entries to the runway


**Constraints**

✓ No more than two routes merge at a point
✓ Merge point separation
✓ No sharp turns
✓ Obstacle avoidance (static)
✓ STAR/SID separation

**Objectives**

✓ Minimize total tree weight
✓ Minimize the sum of the total paths
RECAP: Arlanda Airport TMA (19R): solutions

Pareto frontier:

Pareto optimal solutions:
Re: Grid-based IP formulation

✓ Square grid in the TMA
✓ Snap locations of the entry points and the runway onto the grid
✓ Side of the grid: L (for safe separation)
✓ Every grid node connected to its 8 neighbors
NEW: optimal time-separated demand-weighted -- Problem description

**Given**

✓ location and direction of the airport runway
✓ locations of the entry points to the TMA
✓ times aircraft arrivals at the entry points for a fixed time period

**Output**

Optimal arrival tree that merges traffic from the entries to the runway and ensures safe aircraft separation for the given time period
New: Dynamic Demand-driven Arrival Routes

**Input +:**
Aircraft arrivals for a given period

**Output:**
arrival tree = a set of optimal demand-weighted aircraft trajectories

optimized w.r.t. the traffic demand during the given period

**Data:** EUROCONTROL DDR
Constraints

OLD:
✓ No more than two routes merge at a point
✓ Merge point separation
✓ No sharp turns
✓ Obstacle avoidance (static)
✓ STAR/SID separation

NEW (DASC’18):
✓ Temporal separation of all aircraft along the routes
Idea: temporal aircraft separation

A1 - airplane 1 starts from b3
A2 - airplane 2 starts from b4
M - merge point
t = 1

If

A1 starts at t = 1
If

A1 starts at $t = 1$
If

$A_1$ starts at $t = 1$
If
A1 starts at $t = 1$
t = 5

If

A1 starts at t = 1
If

A1 starts at $t = 1$

A2 starts at $t = 6$
If

A1 starts at $t = 1$

A2 starts at $t = 6$

then

At $t = 7$ they meet at the merge point $M$
If

$A_1$ starts at $t = 1$

$A_2$ starts at $t = 6$

then

At $t = 7$ they meet at the merge point $M$

$\Rightarrow$ COLLISION
Tree adjustment
If $A_1$ starts at $t = 1$
If

A1 starts at $t = 1$
If $A_1$ starts at $t = 1$
If $A_1$ starts at $t = 1$
If $A_1$ starts at $t = 1$
If

A1 starts at \( t = 1 \)

A2 starts at \( t = 6 \)
If

A1 starts at t = 1

A2 starts at t = 6
If

A1 starts at $t = 1$

A2 starts at $t = 6$

then

At $t = 7$ they do not meet at the merge point $M$

COLLISION AVOIDANCE AUTOMATED
Objective

Minimize the sum of trajectory lengths flown by all aircraft

= Minimize the demand-weighted distances

for the given time period!
Automatic Time Separation

✓ Discrete time (t= 1, 2, 3,.. n)

✓ Simplified aircraft speed profile (currently one cell = 1 time unit)

✓ Required time separation of S=1 step in a grid cell
Problem formulation and solution

✓ Formulated as MIP (Mixed Integer Program)
✓ Based on flow MIP formulation for Steiner trees
✓ NP-hard to in general
✓ Solved using Gurobi solver
✓ Run on a server with two 10-core Intel E52650v3 2.3 GHz CPUs, 64 Gb and 1.7 TB temporary disc space
Experimental Evaluation: *synthetic data*
Proof of concept: Time separation example

**b4:** $t = 1, 3, 6, 9$

**b1:** $t = 2, 5, 8, 11$

**b4:** $t = 1, 3, 6, 9$

**b1:** $t = 1, 3, 6, 9$
Experimental Evaluation: *synthetic data*

Proof of concept: Demand-Weighted solution
Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

6-7 am

7-8 am
Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

8-9 am

12-1 pm
Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

3-4 pm

4-5 pm
Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017
Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

EXAMPLE TIME SCHEDULE FOR 10 AIRCRAFT
ARRIVED BETWEEN 6 and 7 am on October 4, 2017

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Entry point</th>
<th>Entry time</th>
<th>Simulated time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M1</td>
<td>M2</td>
</tr>
<tr>
<td>a1</td>
<td>south</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>a2</td>
<td>south</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>a3</td>
<td>south</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>a4</td>
<td>north</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>a5</td>
<td>north</td>
<td>11</td>
<td>x</td>
</tr>
<tr>
<td>a6</td>
<td>east</td>
<td>27</td>
<td>x</td>
</tr>
<tr>
<td>a7</td>
<td>east</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>a8</td>
<td>west</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>a9</td>
<td>west</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>a10</td>
<td>north</td>
<td>30</td>
<td>x</td>
</tr>
</tbody>
</table>

6-7 am
Conclusions

✓ Dynamic mathematical framework for airspace optimization
✓ Automated space and time separation (optimal)
✓ Demand-driven
✓ Improved predictability
✓ Enable TMA capacity evaluation
✓ High flexibility
Future Work

✓ Realistic aircraft slow down procedures
✓ Uncertainties due to variations in arrival times
✓ Dynamic obstacle avoidance
✓ Uncertainties due to changing weather
BAD WEATHER AVOIDANCE AUTOMATED
BAD WEATHER AVOIDANCE AUTOMATED
BAD WEATHER AVOIDANCE AUTOMATED
Future Work

✓ Realistic aircraft slow down procedures
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Thank you!
Future Work

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- Uncertainties due to variations in arrival times
- Dynamic obstacle avoidance
- Uncertainties due to changing weather

Thank you!

Questions?