Self-Reorganized Supporting Tools for Conflict Resolution in High-Density Airspace Volumes

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Air Traffic Management Research and Development Seminar
27-30 June, 2017
Seattle, WA, USA
Overview

Introduction and challenges

Ecosystem Concept Definition

Spatio-Temporal Interdependencies

Compulsory Resolution

Conclusions and Future Work
Introduction: Problem Scope (I)

- Lack of effective integration of DST’s supporting the safety net

- Continuous pressure on Separation Management from Area Control Centre (ACC)

- Increased traffic demand (50% increased number of flights by 2035 comparing to 2012.)

- Improper separation due to insufficient time leads to TCAS activation

- Collision avoidance produces inefficient trajectory amendment — maneuver (vertical rate change)
Designed for operations in traffic densities of 0.3 ac/NM²
Excellent performances for pair-wise encounters
Operational logic drawbacks due to induced collisions in some traffic scenarios
Currently non-compliant with separation management layer

Introduction: Problem Scope (II)
Introduction: Challenges

How to tackle the ATM scalability problem?
How to take advantage of Aircraft capabilities?
How to improve the quality of the conflict resolution?
How to support a smooth transition to a seamless safety net
Introduction: Framework

To perform a flight efficient, safe collaborative and supervised separation management, operationally integrated to trajectory management and collision avoidance.
Introduction: Framework

MTCD (≥ 15') ➔ EC. LAT (5') ➔ STCA (≥ 90'') ➔ CA (< 60'') ➔ CPA

Time

MTCD ➔ LAT ➔ ecosystem ➔ STCA ➔ TCAS ➔ CPA

CA

SM
Ecosystem concept definition

- Proposed ecosystem framework claims for a collaborative and proactive SM system considering a socio-technological approach, in which both human behavior and automation play important role.
Ecosystem concept definition

- Ecosystem creation algorithm: approach to the evaluation of the ecosystem complexity metric (ECM)

- Operational integration of seamless safety procedures in a way that aircraft involved in a pairwise encounter, together with the aircraft in the surrounding volume, behave as a stable conflict free “ecosystem”

- Ecosystem: set of aircraft, with self-automated capabilities, that form a cost-efficient SM system for finding the optimal resolutions compromise

- Intelligent agents can communicate with each other to safely make the best use of existing airspace capacity
## Ecosystem creation (I)

### Traffic extraction
- DDR2 data (24h-operations)
- Filtering above FL245 and within time interval

### Intent-based conflict detection
- Pairwise encounters and over-takings, based on look-ahead time (LAT)
- Intents of two approaching aircraft with predicted loss of standard separation minima

### Cluster creation
- Extracted trajectories filter in time and space around detected conflict
- Identification of cluster members through 4D stamps inside cluster volume

### Ecosystem creation
- Cluster trajectories with potential spatiotemporal interdependencies (STI) through maneuverability metrics
- Identification of ecosystem members through 4D stamps inside cluster volume
Ecosystem creation (II)
Traffic extraction

Traffic queries in a full day of operations over European airspace

Traffic flow using 2-hour time filter in Europe

Scenarios generated using historical DDR2 data, planned 4D trajectories (RBTs) in s06 model 1 (m1) data format

Mapped pairwise conflicts inside one extracted airspace volume
Cluster creation (I)

- Formed around each detected conflict, timely based on LAT prediction interval \([t_{\text{conflict}} - 300'', t_{\text{conflict}}]\)
- Spatially structured by adding safety distances (buffers)
- Defined as set of aircraft whose RBT elements (WPs) are identified inside computed volume (pairwise encounter + surrounding traffic - ST)

Procedure:

- computation of \([t_{\text{conflict}} - 300'', t_{\text{conflict}}]\) from the CD
- find 3D points at \([t_{\text{conflict}} - 300'', t_{\text{conflict}}]\): LATP\(_1\) - CPA\(_1\) - LATP\(_2\) - CPA\(_2\)
- Compute the spatial cluster boundaries by identifying \(\lambda_{\text{min}}, \lambda_{\text{max}}, \phi_{\text{min}}, \phi_{\text{max}}, h_{\text{min}}\) and \(h_{\text{max}}\).
- Construct the cluster coordinates (box-shaped volume) by computing cluster safety parameters
Cluster creation (II)

- \( \varphi_b = \varphi_{\text{min}} - 10 \text{[NM]} \)
- \( \varphi_u = \varphi_{\text{max}} + 10 \text{[NM]} \)
- \( \lambda_b = \lambda_{\text{min}} - 10 \text{[NM]} \)
- \( \lambda_u = \lambda_{\text{max}} + 10 \text{[NM]} \)
- \( h_b = h_{\text{min}} - 2000 \text{[ft]} \)
- \( h_u = h_{\text{max}} + 2000 \text{[ft]} \)

- \( \varphi_b - \varphi_u \) (latitude column);
- \( \lambda_b - \lambda_u \) (longitude column);
- \( h_b - h_u \) (altitude column).

- Identify all 4D points inside volume and match them with corresponding flight IDs
Extended cluster creation

- Applies the same procedure as cluster creation by increasing the metric values

\[
\begin{align*}
\varphi_b' &= \varphi_{\text{min}} - 15[\text{NM}] \\
\varphi_u' &= \varphi_{\text{max}} + 15[\text{NM}] \\
\lambda_b' &= \lambda_{\text{min}} - 15[\text{NM}] \\
\lambda_u' &= \lambda_{\text{max}} + 15[\text{NM}] \\
h_b' &= h_{\text{min}} - 3000[\text{ft}] \\
h_u' &= h_{\text{max}} + 3000[\text{ft}] \\
\end{align*}
\]

- \(\varphi_b' - \varphi_u'\) (latitude column);
- \(\lambda_b' - \lambda_u'\) (longitude column);
- \(h_b' - h_u'\) (altitude column).

- Identify all 4D points inside volume and match them with corresponding flight IDs
Ecosystem creation (I)

- Maneuverability metrics:

  L: Left heading with an angle of +15°
  R: Right heading with an angle of -15°
  C: Climb with a vertical rate of +500 ft/min
  D: Descent with a vertical rate of -500 ft/min
Ecosystem creation (II)

- Spatially-temporal interdependencies: applied maneuver generates conflict interval with neighboring aircraft

- Time stamp overlap with respect to standard separation criteria: 5 NM horizontally, 1000 ft vertically (no RVSM considered)
Ecosystem creation (III)

Generation of STI matrix table:

\[ A/C_i \leftrightarrow \text{maneuver} \implies A/C_j [t_{Sconf}, t_{Econf}] \]
Spatiotemporal interdependencies (STI)

- Example: horizontal plane search

![Diagram showing STI example]

- Conflict interval 1
- Conflict interval 2
Ecosystem deadlock instant (EDE)

*Key issue:* to identify the time limit above which induced collision could emerge due to a conflict avoidance maneuver. This time limit is called ecosystem deadlock event (EDE) and depends on the geometric profiles of the ecosystem trajectories and aircraft closure rates and performance. EDE is computed and triggered by the ATC and characterized by the time instant at which at least one ecosystem member cannot perform any feasible maneuver leading to the conflict-free solution.
Simulation & results (I)

- Simulation inputs:
  1. Historical traffic dated on 12/01/2017, with s06.m1 data model
  2. Total number of RBTs: 24570
  3. Traffic extraction set to 120’, in the selected period 08.00 - 10.00
     clustering performed for different minimum FLs, i.e. from FL200 to FL350

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<th>FL</th>
<th>Traffic extraction and conflict detection: 12/01/2017_m1</th>
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</tr>
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<td>290</td>
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</tr>
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Simulation & results (II)

### cluster structure above FL200

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### cluster structure above FL300

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![Clustering structure above FL200](image1)

![Clustering structure above FL300](image2)
Simulation & results (III)

- Analysis of two scenarios:

**Scenario I above FL210**

<table>
<thead>
<tr>
<th>A/C</th>
<th>( \phi_1 ) [°]</th>
<th>( \lambda_1 ) [°]</th>
<th>( h_1 ) [ft]</th>
<th>( t_1 ) [s]</th>
<th>( \phi_2 ) [°]</th>
<th>( \lambda_2 ) [°]</th>
<th>( h_2 ) [ft]</th>
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**Ecosystem interdependencies**

<table>
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<tr>
<th>A/C</th>
<th>L</th>
<th>R</th>
<th>C</th>
<th>D</th>
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<tbody>
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<td>2 [33974, 34130]</td>
<td>2 [33969, 34130]</td>
<td>2 [33969, 34130]</td>
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<tr>
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<td>4 [34021, 34090]</td>
<td>-</td>
<td>-</td>
<td>1 [33969, 34107] 2 [33969, 34090]</td>
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<tr>
<td>4</td>
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<td>-</td>
<td>3 [34021, 34090]</td>
<td>-</td>
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<tr>
<td>5</td>
<td>-</td>
<td>3 [34021, 34090]</td>
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<tr>
<td>6</td>
<td>-</td>
<td>3 [33969, 34040] 5 [34090, 34093]</td>
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Simulation & results (IV)

Scenario II above FL240

<table>
<thead>
<tr>
<th>A/C</th>
<th>4D elements of ecosystem members</th>
<th>Ecosystem interdependencies</th>
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<tr>
<td></td>
<td>$\phi_1$ [°]</td>
<td>$\lambda_1$ [°]</td>
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<tr>
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Scenario I

Scenario II
Simulation & results (V)

Analysis of STIs for Scenario I with respect to SSM (5 NM horizontally and 1000 ft vertically)
Ecosystem resolution
Conclusions

The proposed framework rely on the EDE computation which is required to enhance SM by means of agent technologies as dynamic demand-capacity balance to solve conflicts at tactical level by identifying and tracking the ecosystem trajectories, in which the airline business models and preferences can be used to reach a resolution agreement before EDE activation.
Future Work

Implementation of different resolution policies enhancing aircraft with agent negotiation capacity considering present ATC situational awareness
Future Work
Many thanks for your attention!

Questions?