Hot Spot Identification & Mitigation at Strategic Level by Small Changes in Aircraft Time of Arrival at Junction

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Research Motivation

- **Challenge**: Tactical actions taken by the Air Traffic Controllers to resolve A/C potential conflicts are the main bottleneck of the current ATM system.

- **Solution**: Trajectory Based Operations (TBO) Concepts: Trajectory management at Strategic level.
Purpose of the Research

- To reduce the probability of ATCO’s tactical interventions at strategic level.

- Propose a new ATFCM metric for demand measure in order to change the current airspace capacity limiting factor, in line with TBO.
Background

- **Strategic Management Vs. Tactical Management**

  - **Involved Actors:**
    - ATFCM
    - ATC

  - **Time to React:**
    - Strategic (Pre-Flight)
    - Tactical: During Flight

  - **Relevancy**
    - Increase

  - **Objectives**
    - ATM Invariant

  - **Functions**
    - Separation Management (SM)

  - **Trajectory Based Operations**
    - DCB to Avoid Sector overload
    - Shift SM functions to Strategic Level

  - **Flight Efficiency**
    - Increase

  - **Airspace Based Operations**
Paradigm Shift: Airspace Based Ops to Trajectory Based Ops

**Behavioral Change:**

- **Strategic Level:** Trajectory Incompatibilities are not known in advance.
- **Tactical Level:** It is up to the ATCO to detect and resolve any potential conflicts.
- **Airspace Capacity:** Limited by ATCO tactical interventions to resolve potential conflicts in a sector.

**Paradigm Shift:**

- **Strategic Level:** Trajectory Incompatibilities are detected & mitigated.
- **Tactical Level:** Potential conflicts are radically reduced, ATCO monitors the traffic flow.
- **Airspace Capacity:** Is not limited by ATCO tactical interventions in a sector.
Proposed Approach

- Airspace Topology
Proposed Approach

\[ \tau_0 = (TOA_i - TOA_j) \Rightarrow \text{Initial separation at Junction before TOA/Speed Changes are applied} \]

\[ \tau_p = (t_i - t_j) \Rightarrow \text{Required Minimum safe time separation at Junction} \]

**LP Optimisation Tool:**
- Minimise total amount of Distance-weighted speed changes: \( J = \sum_i \sum_m \delta V_{im}^{m+1} \cdot d_{im}^{m+1} \)
- Speed changes are bounded below a given threshold: \( \delta V_{im}^{m+1} \leq 0.0X \cdot V_{im}^{m+1} \).
- Departure & TTA are maintained as constraints.
- The Initial Time Separation at Junction between any two successive aircraft before speed/TOA changes are randomly generated within a given time interval “\( \tau_0 \)“.
- New TOA will be issued by NM to the Aircraft to be included in the new RBT.
Proposed Approach

How to quantify "τ_p" in the presence of uncertainty in A/C’s Time of Arrival at Junction (TOA), that minimises ATC tactical Interventions?

Deviations in the A/C Time of Arrival (TOA) at Junction

<table>
<thead>
<tr>
<th>Uncertainty at the junction</th>
<th>Standard deviation specifications &amp; Required Operation/performance conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C Lateral deviation</td>
<td>( \sigma_{T\text{l},j} = \sqrt{2} \times \frac{\sigma_{LD}}{V_{i,j} \times \sin(\alpha_j)} = 30 \text{ sec} )</td>
</tr>
<tr>
<td>Initial time deviation</td>
<td>( \sigma_{T\text{2i},j} = 1 \text{ min} )</td>
</tr>
<tr>
<td>Along-track time deviation</td>
<td>( \sigma_{T\text{3i},j} = \frac{d_{i,j}}{V_{i,j}^2} \times \sigma_{VI,j} = 1 \text{ min} )</td>
</tr>
<tr>
<td>Combined Time Deviation</td>
<td>( \sigma_T = 1.5 \text{ min} )</td>
</tr>
</tbody>
</table>
**Proposed Approach**

- **Minimum Time Separation** ($\tau_p$) & **Probability Of Collision** (PC)

  $\tau_p = \sqrt{-2(\sigma_{T_i}^2 + \sigma_{T_j}^2) \ln[p_c] \sqrt{2\pi(\sigma_{T_i}^2 + \sigma_{T_j}^2)}}$

- Minimum safe separation Interval at Junction: $\tau_p \approx 9$ minutes
- Probability of collision : $PC = 10^{-5}$
- Junction inbound capacity $Q_l_m = 1/\tau_p = 6$ A/C per Hour
Example Solutions

- **Number of A/C in a Bunch that Can be Realistically De-conflicted**
  
  **Bunch**: Sequence of two or more aircraft inbound an active junction for a given period of time.
  
  \[ \tau_0 \geq [0, 9] \Rightarrow \text{All in bound traffic in a Bunch are initially in conflict} \]

![Graph showing optimal speed changes for conflict removal at junction (A/C Normal Speed)]

- **Speed changes per aircraft for 12A/C and 15 A/C in a bunch**
Example Solutions

- Monotonic Increase of Speed/TOA changes when $\tau_0 < [0 \ 9]$
Example Solutions

- Modulation of Speed/TOA Changes & Steady State

Oscillated behavior of speed changes when $\tau_0 \geq [0-9]$

Speed changes reaches steady state when $\tau_0 \geq [0-18]$

Assumption: Free-Routing is Assumed
Conclusions

- New ATFCM metric for demand measure based on Hot Spot identification & mitigation at strategic level is proposed.

- The minimum safe separation interval at junction: $\tau_p \approx 9$ minutes that gives a probability of collision of $PC=10^{-5}$ is established.

- The mitigation actions are based on establishing new TOA at Junction computed using a basic LP optimisation.

- Monotonic increase of TOA/Speed changes for first and last aircraft in a bunch is changed by establishing specific traffic demand and operational conditions.

- Conditions under which TOA/Speed changes reach the stable state are established.

- Further Work: Run the model based on a larger actual airspace structure such as ECAC structure
THANK YOU