An analysis of sequencing arrivals at three European airports

R. Christien, E. Hoffman, A. Trzmiel, K. Zeghal

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Introduction

• Objective: analysis of sequencing during peak periods of arrival flights at three European airports
  • Frankfurt Main, London Heathrow and Madrid Barajas
  • More than 24000 aircraft pairs

• Motivation: to better understand and characterise how sequencing is performed in dense and complex environments

• Method
  • purely data driven
  • focuses on the dynamic of spacing over time between consecutive aircraft
  • investigate spacing convergence and monotonicity
How to define spacing?

- The controller builds his/her own estimation of the spacing during the sequencing… It is part of the cognitive process and is not accessible.

- How to define spacing between two aircraft vectored on different paths with resume paths unknown in advance?
Minimum time and spacing

\[ \text{spacing deviation (t)} = \text{5 – 4 min} \]

\[ \text{leader (t – 90s*)} \]

\[ \text{leader (t)} \]

\[ \text{trailer (t)} \]

- aircraft trajectory
- fastest trajectory
- other trajectories

*required spacing

\[ \text{spacing deviation (t)} = \text{min time (trailer (t)) – min time (leader (t – s))} \]
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
Spacing : an example
Spacing : an example
Spacing : an example
Spacing: an example, divergence
Spacing : an example, all divergences
Spacing: an example, cumulated divergences
Case study

- 3 European airports
  - Madrid Barajas (LEMD)
  - Frankfurt Main (EDDF)
  - London Heathrow (EGLL)

- About 130,000 arrival flights
  - More than 40,000 for each destination
  - Position reports, January to March 2017, within 80NM from destination

- Data filtering
  - Only major flows considered (more than 80% of dataset)
  - Go-arounds, exceptional short or long flying time
  - Aircraft without data close enough to the final approach fix

- About 92,000 flights (>70%) after filtering, available for min. time estimates
## Trajectory samples

<table>
<thead>
<tr>
<th>LEMD</th>
<th>EDDF</th>
<th>EGGL</th>
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![LEMD Trajectory Samples](image1.png)

![EDDF Trajectory Samples](image2.png)

![EGGL Trajectory Samples](image3.png)
Madrid, minimum time maps

Minimum time per flow

Runways: 32
Frankfurt, minimum time maps

Minimum time per flow

Runways: 07

Runways: 25
London, minimum time maps

Minimum time per flow

Runways: 09

Runways: 27
Peak period selection and aircraft pairs

• Identify peak hours
  • Periods with average additional time above 3rd quartile for the destination (red line on graph)

• During the peak hours, select consecutive flights with fly-over time difference at final < 200s,
  • About 24 000 flight pairs
Spacing deviation

Spacing deviation samples, median and 90% containment

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Spacing deviation at 10min

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Spacing deviation at 5min

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Spacing deviation: typical cases identified by clustering

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Extra variation

Extra variation of spacing samples, median and 90% containment

Cumulated spacing variation (minute)

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Time to Final Approach Fix (minute)

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Extra variation, 95% values at 5 and 10 minutes to final

Peak period of 5 (LEMD), 4 (EDDF) and 12 (EGLL) minutes
Conclusion and next steps

- **Key results**
  - *progressive convergence* with spacing deviation
    - containment: ±2.5min at 10min to final, ±45s at 5min to final
    - *reflect the level of bunching to be resorbed during peak periods*
  - *non monotonous convergence* with extra spacing variations
    - maximum (95% percentile): 2.5min at 10min to final, 40s at 5min to final
    - *reflect the level of sensitivity while acquiring and maintaining spacing in dense and complex environments*

- **Future work**
  - understanding the relation between spacing deviations and spacing variations
  - investigating how this approach may help identifying best practices and assessing impact of a change
  - …