Sector Demand Analysis under Weather Uncertainty (TBO-Met Project)

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A methodology to assess the uncertainty of sector demand when meteorological uncertainty is taken into account.

A probabilistic sector demand prediction is obtained from the uncertainty of the individual trajectories.

The approach is based on the statistical characterization of the entry and occupancy counts.
Outline

1. Methodology for Sector Demand Analysis
2. Application: Sector Demand Analysis at Pre-tactical Level
3. Application: Sector Demand Analysis at Tactical Level
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1. Methodology for Sector Demand Analysis
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3. Application: Sector Demand Analysis at Tactical Level
General Scheme

- Definition of Scenario
- Meteorological Data Processing
- **Trajectory Predictor**
  For each flight and for each atmospheric realization, it computes a different possible aircraft trajectory $x_{ij}$.
- Sector Demand Analysis

ATC sector

Definition of scenario

flights

weather forecasts

Trajectory Predictor

meteorological data

aircraft trajectories $x_{ij}$

Meteorological Data Processing

Sector Demand Analysis
Definitions and Hypotheses

• **Sector geometry**: fixed and does not change with time. The effects of opening/closing sectors are not analysed.

• $m$: number of flights.

• $n$: number of weather realizations (members of the EPS or Nowcast variations).

• $x_{ij}(t)$: position of flight $i$ ($i = 1, ..., m$) for member $j$ ($j = 1, ..., n$) at time $t$

  $$x_{ij}(t) = [\lambda_{ij}(t), \phi_{ij}(t), h_{ij}(t)]$$

  where $\lambda$ is the longitude, $\phi$ is the latitude, and $h$ is the pressure altitude.

For each flight $i$, one has $n$ trajectories $x_{ij}$, as many as weather realizations.
Entry/Exit Times

• For each trajectory $x_{ij}$, one has an entry/exit time to the sector $t_{ij,E}/t_{ij,X}$ and its associated entry/exit point, $x_{ij}(t_{ij,E})/x_{ij}(t_{ij,X})$.

• The $n$ different entry/exit times can be statistically characterized:
  
  • **Average entry/exit time** for flight $i$
    \[
    t_{i,E} = \frac{1}{n} \sum_{j=1}^{n} t_{ij,E} \quad t_{i,X} = \frac{1}{n} \sum_{j=1}^{n} t_{ij,X}
    \]

  • **Dispersion of the entry/exit time** for flight $i$
    \[
    \Delta t_{i,E} = \max_{j} t_{ij,E} - \min_{j} t_{ij,E} \quad \Delta t_{i,X} = \max_{j} t_{ij,X} - \min_{j} t_{ij,X}
    \]
Entry/Occupancy Count

- **Entry/occupancy count**: number of flights entering/inside the sector during a selected time period, $P_k$.
- Because the entry and exit times are uncertain, then the entry and occupancy counts are also uncertain. The aircraft can enter or exit the sector in different time periods.
- The duration of the time periods plays a key role in the uncertainty of the counts. If it is very small, then the aircraft may enter/exit the sector in two or more consecutive time periods.
Example: Entry Count from EPS

- Entry count for ensemble member $j$ and time period $P_k$
  \[
  E_j(P_k) = \sum_{i=1}^{m} E_{ij}(P_k)
  \]
  where $E_{ij}(P_k)$ is an entry function for flight $i$, ensemble member $j$, and time period $P_k$
  \[
  E_{ij}(P_k) = \begin{cases} 
  1, & \text{if } t_{ij,E} \in P_k \\
  0, & \text{otherwise}
  \end{cases}
  \]

- Statistical characterization
  - Mean value
    \[
    \bar{E}(P_k) = \frac{1}{n} \sum_{j=1}^{n} E_j(P_k)
    \]
  - Max and min values
    \[
    E_{\max}(P_k) = \max_j E_j(P_k) \\
    E_{\min}(P_k) = \min_j E_j(P_k)
    \]
  - Dispersion
    \[
    \Delta E(P_k) = E_{\max}(P_k) - E_{\min}(P_k)
    \]
  - Probability of exceeding capacity
    \[
    P[E(P_k) > a] = \frac{\text{number of } E_j(P_k) > a}{n}
    \]
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Application

• The demand of an en-route sector is analysed for a whole day, 01 September 2016 (from 00:00 to 24:00), when predicted the day before, 31 August 2016 at 00:00.

• Two scenarios: routes planned for two different values of $dp$:
  
  • $dp = 0$ (time dispersion is not reduced), and
  • $dp = 20$ (time dispersion is reduced).

  In both cases, $cp = 0$. 
Traffic Scenario: ATC Sector

- ATC sector: **LECMSAU**.
- From FL345 to FL460.
- Declared capacity: 36 flights/hour.
Traffic Scenario: Weather Forecasts

- **ECMWF-EPS**, composed of 50 perturbed members.
- **Release time**: 00:00 on 31-Aug-2017.
- **Time steps**: 12, 18, 24, 30, 36, 42, 48, 54, and 60 hours.
- **Met data**: meridional and zonal winds.
- **Example**, mean values and spreads at 36 hours (difference between max and min):
Traffic Scenario: Flights

- Number of flights: 328 flights.
- Flight information (coordinates of origin and destination, departure time) obtained from NEST.
- All flights at constant pressure altitude (200 hPa). Cruise speed from BADA 3.13.

\[ dp = 0 \]

\[ dp = 20 \]
Results: Entry Time

\[ \Delta t_E \text{ [s]} \]

\begin{align*}
\Delta t_E &= 156.4 \\
\bar{t_f} &= 10759
\end{align*}

\[ \text{Diff} = -30.6 \quad +382.5 \]

\[ dp = 0 \quad dp = 20 \]

\[ d_P = 0 \quad d_P = 20 \]
Results: Entry Count (I)

\[ dp = 0 \]

\[ \delta t = 60 \text{ min} \]

\[ \delta t = 30 \text{ min} \]

\[ \delta t = 10 \text{ min} \]
Results: Entry Count (II)

\[ \delta t = 60 \text{ min} \]
Results: Entry Count (III)

<table>
<thead>
<tr>
<th>$dp = 0$</th>
<th>$\Delta E$</th>
<th>$dp = 20$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,83</td>
<td>0,50 ↓</td>
<td></td>
</tr>
<tr>
<td>0,99</td>
<td>0,69 ↓</td>
<td></td>
</tr>
<tr>
<td>0,90</td>
<td>0,50 ↓</td>
<td></td>
</tr>
</tbody>
</table>
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**Application**

- The **demand** of an en-route sector is **analysed tactically**, on 19 December 2016, from 06:00 to 13:00.

- The prediction of the sector demand is **updated every 10 minutes**: new possible deviation trajectories are computed, according to the release of new Nowcasts and the movement of the aircraft. The deviation trajectories are generated once the aircraft enters an **extended area** around the sector.

- Two scenarios: routes planned for **two different values of \(cp\):**
  
  - \(cp = 0\) (convection risk is not reduced), and
  
  - \(cp = 0.005 \text{ s/m}\) (convection risk is reduced).

  In both cases, \(dp = 0\).
Traffic Scenario: ATC Sector

- ATC sector: LECBLVU.
- From FL345 to FL460.
- Declared capacity: 37 flights/hour.
Traffic Scenario: Weather Forecasts

- The reference trajectories are obtained considering ECMWF-EPS (for wind uncertainty) and GLAMEPS (for probability of convection).

- Nowcasts are provided by AEMET:
Traffic Scenario: Flights

- Number of flights: 257 flights.
- Flight information (coordinates of origin and destination, departure time) obtained from NEST.
- All flights at constant pressure altitude (200 hPa). Cruise speed from BADA 3.13.
Results: Deviation trajectories
Results: Occupancy Count (I)

08:30

08:40
Results: Occupancy Count (II)

- Average dispersion of the occupancy count (from 07:30 to 11:00, the period with highest storm activity):

  **Average dispersion** is reduced from 0.52 flights for $cp = 0$ to 0.37 flights for $cp = 0.005$ s/m
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Thank you very much for your attention!