Arrival trade-offs considering total flight and passenger delays and fairness

Adeline Montlaur – Luis Delgado
Universitat Politècnica de Catalunya
University of Westminster
Total flight delays

$$D_{\text{Flight}} = \sum_f (CTA(f) - STA(f)) + 1.8(CTA(f) - LTA(f))$$

Primary delay  Reactionary delay
Total passenger delays

\[ D_{PAX} = \sum_f (PAX_{arr}(f)(CTA(f) - STA(f))) + PAX_{connec} \text{PropagDelay}(f, CTA(f)) + PAX_{dep}(f)(CTA(f) - LTA(f)) \]

Arrival delay  Missed connections delay  Departure delay

Fairness

- Fairness as total deviation with respect to RBS

\[ D_{RBS} = \sum_f (|CTA(f) - RBS(f)|) \]
Overview of presentation

- Multi-objective optimisation
  - Flights and passenger trade-off
  - Fairness trade-off
- Fairness vs. efficiency trade-off
  - Price of fairness
  - Price of efficiency
- Discussion of results
- Conclusions and future work
Multi-objective optimisation

• Problem defined as GHP solved with integer programming

\[ \text{Obj}(\alpha, \beta, \gamma) = \alpha D_{RBS} + \beta D_{RAX} + \gamma D_{Flight} \]

Fairness Passenger Flight

• Convex combination to provide Pareto for *a posteriori* articulation of preferences

\[ \alpha + \beta + \gamma = 1 \quad 0 \leq \alpha, \beta, \gamma \leq 1 \]
Multi-objective optimisation

- $Obj_{PAX}(\alpha, \beta, \gamma)$: total passenger delay → optimal with $\beta = 1 \rightarrow Opt_{PAX}$
- $Obj_{Flight}(\alpha, \beta, \gamma)$: total flight delay → optimal with $\gamma = 1 \rightarrow Opt_{Flight}$
- $Obj_{Fair}(\alpha, \beta, \gamma)$: total deviation from RBS → optimal with $\alpha = 1 \rightarrow Opt_{Fair}$
Multi-objective optimisation

- Arrivals at Paris CDG 12SEP14 5h00 – 11h00 GMT
- ATFM regulation 6h00 – 8h00 GMT

<table>
<thead>
<tr>
<th>(min)</th>
<th>Obj_{Fair}</th>
<th>Obj_{Flight}</th>
<th>Obj_{PAX}</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = 1 )</td>
<td>0</td>
<td>3774.8</td>
<td>589102</td>
</tr>
<tr>
<td>( \beta = 1 )</td>
<td>2601</td>
<td>3788.4</td>
<td>239594</td>
</tr>
<tr>
<td>( \gamma = 1 )</td>
<td>2057</td>
<td>2553.4</td>
<td>446760</td>
</tr>
</tbody>
</table>
Multi-objective optimisation

- Flight vs Passenger trade-off

\[ \alpha = 0 – \text{Only flight and pax delay considered} \]
Multi-objective optimisation

- Flight vs Deviation RBS trade-off

\[ \beta = 0 \text{ – Only flight and deviation RBS considered} \]
Multi-objective optimisation

- Passenger vs Deviation RBS trade-off

\[ \gamma = 0 \rightarrow \text{Only pax and deviation RBS considered} \]
Multi-objective optimisation

- Flight vs Passenger vs Deviation RBS
Fairness vs efficiency trade-off

\[ POF(U, \alpha) = \frac{\text{SYSTEM}(U) - \text{FAIR}(U, \alpha)}{\text{SYSTEM}(U)} \]

**Fairness vs efficiency trade-off**

\[
POF(U, \alpha) = \frac{SYSTEM(U) - FAIR(U, \alpha)}{SYSTEM(U)}
\]

\[
POE(U, \alpha) = \frac{\max_{u \in U} \min_{j=1,\ldots,n} u_j - \min_{j=1,\ldots,n} z_j(\alpha)}{\max_{u \in U} \min_{j=1,\ldots,n} u_j}
\]

Fairness vs efficiency trade-off

\[ POF(U, \alpha) = \frac{SYSTEM(U) - FAIR(U, \alpha)}{SYSTEM(U)} \]

\[ POE(U, \alpha) = \max_{u \in U} \min_{j=1,\ldots,n} u_j - \min_{j=1,\ldots,n} z_j(\alpha) \]

Fairness vs efficiency trade-off

\[
POF_{\text{Flight}}(\alpha, \beta, \gamma) = \frac{\text{Opt}_{\text{Flight}} - \text{Obj}_{\text{Flight}}(\alpha, \beta, \gamma)}{\text{Opt}_{\text{Flight}}}
\]

\[
POF_{\text{PAX}}(\alpha, \beta, \gamma) = \frac{\text{Opt}_{\text{PAX}} - \text{Obj}_{\text{PAX}}(\alpha, \beta, \gamma)}{\text{Opt}_{\text{PAX}}}
\]

\[
POE(\alpha, \beta, \gamma) = \frac{|\text{Opt}_{\text{Fair}}| - |\text{Obj}_{\text{Fair}}(\alpha, \beta, \gamma)|}{\max(|\text{Obj}_{\text{Fair}}|)}
\]
Fairness vs efficiency trade-off

\[ \alpha \text{ – Deviation RBS} \]
\[ \beta \text{ – Pax total delay} \]
\[ \gamma \text{ – Flights total delay} \]
Fairness vs efficiency trade-off

\( \alpha \) – Deviation RBS
\( \beta \) – Pax total delay
\( \gamma \) – Flights total delay
Fairness vs efficiency trade-off

\[ \alpha \text{ – Deviation RBS} \]
\[ \beta \text{ – Pax total delay} \]
\[ \gamma \text{ – Flights total delay} \]
Discussion of results

- Multi-objective selection of parameters
- Across objectives trade-offs
Discussion of results

- Deviation RBS
- Pax total delay
- Flights total delay
Discussion of results

\[ \alpha \] – Deviation RBS
\[ \beta \] – Pax total delay
\[ \gamma \] – Flights total delay
Discussion of results

\[ \alpha \approx 0.3 \]
\[ \beta \approx 0.6 \]
\[ \gamma \approx 0.1 \]

\[ \alpha \] – Deviation RBS
\[ \beta \] – Pax total delay
\[ \gamma \] – Flights total delay
Discussion of results

\[ \alpha \] – Deviation RBS
\[ \beta \] – Pax total delay
\[ \gamma \] – Flights total delay
Discussion of results

\[ \alpha \] – Deviation RBS
\[ \beta \] – Pax total delay
\[ \gamma \] – Flights total delay
Discussion of results

\( \alpha \) – Deviation RBS
\( \beta \) – Pax total delay
\( \gamma \) – Flights total delay
Discussion of results

\[ \alpha = \text{Deviation RBS} \]
\[ \beta = \text{Pax total delay} \]
\[ \gamma = \text{Flights total delay} \]

\[ \alpha = 1 \]
\[ \beta = 0 \]
\[ \gamma = 0 \]

\[ \alpha = 0 \]
\[ \beta = 0 \]
\[ \gamma = 1 \]

\[ \alpha = 0.3 \]
\[ \beta = 0.6 \]
\[ \gamma = 0.1 \]

\[ \alpha = 0.4 \]
\[ \beta = 0.4 \]
\[ \gamma = 0.2 \]
Conclusions and future work

- Different stakeholders need to be considered when optimising
  - Improvements can be achieved for one stakeholder without significant reducing performance of another
  - But, might have impact on the fairness of the solution
  - Think about the passengers!
  - But, how to share/consider the information?
- Fairness defined as deviation from RBS
  - Still flight-centric approach
  - Other solutions?
- POE and POF allows modellers to *a posteriori identify the different trade-offs*
  - How to better present this information?
- Extend work to other airports/regulations to be analysed
Thanks for your attention
Multi-objective optimisation

- Problem defined as GHP solved with integer programming

\[
Obj(\alpha, \beta, \gamma) = \alpha D_{RBS} + \beta D_{PAX} + \gamma D_{Flight}
\]

Fairness Passenger Flight

- Convex combination to provide Pareto for \textit{a posteriori} articulation of preferences

\[
\alpha + \beta + \gamma = 1 \quad 0 \leq \alpha, \beta, \gamma \leq 1
\]

- Upper-lower-bound transformation

\[
Obj(\alpha, \beta, \gamma) = \alpha \frac{D_{RBS} - D_{RBS}^0}{D_{RBS}^{\max} - D_{RBS}^0} + \beta \frac{D_{PAX} - D_{PAX}^0}{D_{PAX}^{\max} - D_{PAX}^0} + \gamma \frac{D_{Flight} - D_{Flight}^0}{D_{Flight}^{\max} - D_{Flight}^0}
\]
Flights and passengers delays

A. Montlaur, L. Delgado, Delay assignment optimization strategies at pre-tactical and tactical levels, SESAR Innovation Days 2015
Flights and passengers delays

Obj = $\alpha$ Total delay per flight + $(1-\alpha)$ Total delay per passengers
Flights and passengers delays

A. Montlaur, L. Delgado, Delay assignment optimization strategies at pre-tactical and tactical levels, SESAR Innovation Days 2015