Airport Apron Roundabout – Operational Concept and Capacity Evaluation

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Background
Background
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Background
Background

Initially planned conventional intersection

Roundabout – preliminary design
Background

Only lines in use with adopted directions!
Background

• 1\textsuperscript{st} stage in the overall evaluation process – Capacity evaluation

• \textit{The aim:}
  to examine the performance of the roundabout in the MUC environment and to compare it to the conventional intersection under the same operating conditions
Background

• 1st stage in the overall evaluation process – Capacity evaluation

• The aim:
  to examine the performance of the roundabout in the MUC environment and to compare it to the conventional intersection under the same operating conditions

  Roundabout simulation model

  Analytical model for taxiway intersection capacity estimation
Roundabout Operations Model

• Exemption from general practice
• “Visual observations to estimate the respective relative positions”

• Separation
  – Small a/c: A, B and C; Large a/c: D, E and F (ICAO code letters)
  – Nose-to-nose separation:
    • 100m \((40+60)\) if leading a/c is small;
    • 190m \((70+120)\) if leading a/c is large

• General rule for roundabout operations
  aircraft is allowed to enter the intersection if precisely defined restricted sections are unoccupied by other aircraft. FCFS applies on the entrance!
Roundabout Operations Model

- Restricted sections:
  - *In front, Behind and Other*
- Depend on a/c path (entry and exit point) and a/c type
- Defined for 24 origin/destination/a/c type case

**EXAMPLE:** West-North-small a/c
Roundabout Operations Model

- Restricted sections:
  - *In front, Behind and Other*

- Depend on a/c path (entry and exit point) and a/c type

- Defined for 24 origin/destination/a/c type case

- Boundary points
Roundabout Operations Model

- Restricted sections:
  - *In front, Behind and Other*

- Depend on a/c path (entry and exit point) and a/c type

- Defined for **24** origin/destination/a/c type case

- Boundary points

- Independent paths
Restricted sections and independent paths for all 24 O/D/a/c type cases

Roundabout ops model

**EXAMPLE:** West-North-small a/c
Roundabout Simulation Model

• Simulation model (Flexsim 3.02)
  – Roundabout operations model
  – Saturation conditions, FCFS

• Input data:
  – Traffic O/D matrices: outbound and inbound (transposed) peak
  – Fleet mix: 90/10 and 80/20 share of small/large a/c
  – Taxiing speed: 20km/h

• Scenarios: 1. Outbound 90/10
  2. Outbound 80/20
  3. Inbound 90/10
  4. Inbound 80/20

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>E</td>
</tr>
<tr>
<td>S</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>N</td>
<td>25</td>
<td>2.5</td>
</tr>
<tr>
<td>W</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>6</td>
</tr>
</tbody>
</table>
Roundabout Simulation Model

- Simulation results
  - 100 iterations
Roundabout Simulation Model

• Simulation results
  – 100 iterations

About double the current runway system capacity (90 ops/h) and about 50% higher than the future runway system capacity (120 ops/h)!

<table>
<thead>
<tr>
<th></th>
<th>Scen 1</th>
<th>Scen 2</th>
<th>Scen 3</th>
<th>Scen 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>170</td>
<td>149</td>
<td>166</td>
<td>152</td>
</tr>
<tr>
<td>Max</td>
<td>204</td>
<td>189</td>
<td>199</td>
<td>190</td>
</tr>
<tr>
<td>Average</td>
<td>186</td>
<td>173</td>
<td>181</td>
<td>170</td>
</tr>
<tr>
<td>Stdev</td>
<td>7.45</td>
<td>7.67</td>
<td>6.71</td>
<td>6.75</td>
</tr>
</tbody>
</table>
Roundabout Simulation Model

**RWY system capacity**

- current: 90 ops/h (2 parallel RWYs)
- future: 120 ops/h (3 parallel RWYs)

Not expected to become capacity issue at MUC apron, under observed traffic scenarios!
Roundabout vs. Conventional Apron Crossing

\[ \lambda = \frac{1}{t} \]

\( \lambda \) – taxiway intersection entry capacity
\( t \) - mean inter-entry time for all aircraft demanding service

\[ t = \sum_{ij} t_{ij} p_{ij} \]

\( i, j \) - leading and trailing aircraft (described with 3 characteristics: origin, destination and a/c type)
\( t_{ij} \) - time interval between the moments two consecutive aircraft \((i,j)\) start entering the intersection

\[ p_{ij} = p_i p_j \]

\( p_{ij} \) - probability of \((i,j)\) pair appearance
\( p_i \) - probability of leading aircraft \((i)\) appearance
\( p_j \) - probability of trailing aircraft \((j)\) appearance
Roundabout vs. Conventional Apron Crossing

- Multiple entries, multiple exits system
- Inter-entry times determination for \((i,j)\) pair
- Modification with respect to impact of the predecessors to each aircraft pair
- Greatest impact on capacity - “zero” pairs
  \((t_{ij}=0\) i.e. aircraft \(i\) and \(j\) allowed to enter the intersection simultaneously!)
- Additional separation is mainly equal to separation between following aircraft \((j)\) and \((i,j)\) pair predecessor
Predecessor – “zero” pair triplet

**EXAMPLE**

Predecessor-pair ($\Delta t \neq 0$)

\[
N(S) - S(N) - N(S)
\]

$\Delta t = 0$  $\Delta t = 0$

Additional separation included in the calculation with the probability of particular triplet appearance.
Roundabout vs. Conventional Apron Crossing

• Results from analytical model – simplified traffic data:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Roundabout Design</th>
<th>Conventional Design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Inter-entry Time (s)</td>
<td>Intersection Capacity (aircraft/h)</td>
</tr>
<tr>
<td>Scen 1</td>
<td>18.5</td>
<td>194</td>
</tr>
<tr>
<td>Scen 2</td>
<td>19.8</td>
<td>182</td>
</tr>
<tr>
<td>Scen 3</td>
<td>19.6</td>
<td>184</td>
</tr>
<tr>
<td>Scen 4</td>
<td>20.7</td>
<td>174</td>
</tr>
</tbody>
</table>

• Validation:

  – Simulation results with simplified traffic vs. complete traffic
  – Simulation results with simplified traffic vs. analytical model results for roundabout
Simulation with simplified traffic vs. simulation with complete traffic
Roundabout vs. Conventional Apron Crossing

• Validation – summary:

**Approx. 5 aircraft/h difference – less than 3%**

**Approx. 3 aircraft/h or 1.5% difference**

<table>
<thead>
<tr>
<th>Scen</th>
<th>Simulation – Complete Traffic (aircraft/h)</th>
<th>Simulation – Simplified Traffic (aircraft/h)</th>
<th>Analytical Model – Roundabout (aircraft/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scen 1</td>
<td>186</td>
<td>191</td>
<td>194</td>
</tr>
<tr>
<td>Scen 2</td>
<td>173</td>
<td>179</td>
<td>182</td>
</tr>
<tr>
<td>Scen 3</td>
<td>181</td>
<td>186</td>
<td>184</td>
</tr>
<tr>
<td>Scen 4</td>
<td>170</td>
<td>175</td>
<td>174</td>
</tr>
</tbody>
</table>

• Results from analytical model:

<table>
<thead>
<tr>
<th>Scen</th>
<th>Roundabout Intersection Capacity (aircraft/h)</th>
<th>Conventional Intersection Capacity (aircraft/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scen 1</td>
<td>194</td>
<td>217</td>
</tr>
<tr>
<td>Scen 2</td>
<td>182</td>
<td>201</td>
</tr>
<tr>
<td>Scen 3</td>
<td>184</td>
<td>207</td>
</tr>
<tr>
<td>Scen 4</td>
<td>174</td>
<td>195</td>
</tr>
</tbody>
</table>

The capacity of a conventional intersection is approximately 10% higher!
**Discussion and conclusion**

*RWY system capacity*

- current: 90 ops/h (2 parallel RWYs)
- future: 120 ops/h (3 parallel RWYs)

In the context of the airport as a whole: under observed local conditions the difference is not significant enough to reject roundabout for further consideration!
Discussion and conclusion

Fewer merging and crossing points

MUC roundabout project in progress...
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Recorded simulation sample, Scenario 4 - Inbound 80/20

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